EFFECT OF SPATIAL FACTORS ON ISOMETRIC PUSH, PULL, PUSH-UP AND PULL-DOWN STRENGTHS

Pornsiri Jongkol
School of Industrial Engineering, Suranaree University of Technology
Nakhonratchsima, Thailand

Biman Das
Department of Industrial Engineering, Dalhousie University
Halifax, Nova Scotia, Canada
biman.das@dal.ca

The effect of reach levels, horizontal angles and vertical angles on isometric push, pull, push-up and pull-down strengths of males and females in standing and seating positions was determined. As reach level increased, push strength increased. Similar to push strength, pull strength in normal reach was significantly less than that in maximum and extreme reaches. Nevertheless, pull strength in maximum and extreme reach levels were not significantly different, except for the overhead location. Push-up and pull-down strengths mostly decreased with increasing reach levels, except for the overhead location. Vertical angle had a significant effect on strengths. Push, pull, and pull-down strengths increased significantly as vertical angle increased. Push-up strength decreased when vertical angle changed from -20° to 0° and 45°, whereas the greatest strength was found at the overhead location. Horizontal angle had a significant effect on strengths. Push and pull strengths decreased as horizontal angle increased. Push-up and pull-down strengths at 90° and 135° were significantly greater than that at 0°.

INTRODUCTION

Human strength is one of the most critical physical capabilities required to perform manual materials handling tasks. Isometric strength profiles in workspace can be used to design task to avoid overexertion. With controlled experiments, the roles of factors that would affect strengths can be investigated. Isometric strengths are affected by a number of factors including measurement location and direction of exertion (Mital and Kumar 1998). Measurement location can be characterized relative to a person's anthropometry using reach, and vertical and horizontal angles. Direction of exertion can be defined either relative to individual anthropometry using radial push and pull exertions or in vertical and horizontal planes as push-up and pull-down exertions. Knowing the significant impact of these factors on strengths can help to identify the important variables for workstation design for both productivity and comfort. Another factor, which can greatly influence strengths, is body posture, especially the positions of arm and trunk. As a consequence, arm reach and trunk posture during force exertion should be defined precisely. The measurement of strength relative to normal, maximum and extreme workspace reach envelopes is a way to control the confounding effects, if any, in a given result. Strengths in workspace reach envelopes can be used to establish optimum workstation design. Notably push and pull strength capability is related to shoe/floor friction and postural stability (Chaffin et al. 1983). Therefore, force exertions in seated and standing positions should be compared. This will be useful as an aid for task design. The main objectives of this study were to: (1) analyze the significance of location factors including reach, vertical angle, and horizontal angle, on radial push and pull strengths and vertical push-up and pull-down strengths among male and female, and (2) investigate the effect of force direction, position during exertion, and gender on strength data collected under controlled conditions.

METHOD

For this investigation, 15 males and 15 females (college students) participated in the study. A computerized isometric strength measurement system was designed and constructed for the purpose. The four force directions were: push, pull, push-up and pull-down. Push and pull forces were exerted in radial direction, whereas push-up and pull-down are made in vertical direction. The isometric strengths of each force direction were measured at 26 locations for both the standing and seated work positions. The measurement locations were defined by three work design parameters: reach and vertical and horizontal angles. The measurement locations in normal, maximum and extreme workspaces (6, 10 and 10 locations respectively) were not equal. Thus, strength data for each force direction were divided into three sets. For the first data set, the strength values measured in all reach levels at 0° and 45° vertical angles were included. For data analysis, ANOVA (Analysis of Variance) was used and where the significant effect of factors was found, Duncan multiple range test was performed for pairwise comparison.

RESULTS

The research results presented earlier had shown that isometric strength values varied differently for push, pull, push-up and pull-down exertions (Jongkol 2001).

Experimental results for the isometric push, pull, push-up and pull-down strengths are presented below.

Isometric Push Strength

The ANOVA (Table 1) of isometric push strength revealed that posture, gender, reach and vertical and horizontal angles were highly significant. Stated otherwise, these factors had a highly significant effect on isometric push strength. Duncan's test (Table 2) showed highly significant increases from normal reach (66.25 N) to maximum (84.42 N) and extreme reach (95.09 N) for the first data set. For the second and third data sets, isometric strength increased significantly as reach changed from maximum to extreme level. As reach level increased the subjects were able to lean on the handle during force exertion. As vertical angle increased, push strength increased significantly and reached the greatest value at overhead location (Φ= 90° and Θ=90°). At the overhead location, the upper and lower limbs and trunk were aligned with the force direction, thus, increasing the assistance of arm, legs and trunk muscles in force exertion. When horizontal angle increased, strength decreased significantly. This is due to the fact that the subjects noticeably exerted force at the right side of the body with less stability.

Isometric Pull Strength

Due to space limitation, it will not be possible to present the ANOVA and Duncan test results through the tables as shown earlier. However, the main results are highlighted here. ANOVA showed that posture, gender, reach and vertical and horizontal angles ere highly significant in most cases. Pull strength in maximum and extreme reaches were significantly greater that that in normal reach, but they were not significantly different from each other. The probable reason was that instability increased in the extreme reach position, therefore, preventing an increase in pull strength exertion. As vertical angle increased, pull strength significantly increased due to the deployment of body weight. Similar to push strength exertion, pull strength decreased with the increasing horizontal angle.

Isometric Push-up Strength

ANOVA revealed that the effects of posture, gender, reach, vertical and horizontal angles were highly significant. Duncan's test showed that push-up strength in normal reach was significantly greater than that in maximum and extreme reaches. During push-up exertion, normal reach would correspond to the optimal muscle length of elbow strength at this location. At the overhead location, push-up strength was greatest since trunk, upper and lower limbs are aligned with force direction, allowing the use of these muscles to assist in the arm exertion. As vertical angle increased from -20° to 0° and 45°, push-up strength had decreased, probably due to the limited assistance of trunk and lower limbs. Push-up strengths at 90° and 135° were significantly greater than that at 0°. This may be a result of the shorter distance from the handle to the body median line during force exertion at 90° and 135°.

Table1. ANOVA of isometric push strength (Newtons or N)

Source	First data set		Second data set		Third data set	
	df	p value	df	p value	df	p value
Posture	1	0. 01**	1	0. 01**	1	0. 01**
Gender	1	0. 01**	1	0. 01**	1	0. 01**
Reach	2	0. 01**	1	0. 01**	1	0. 01**
Vertical angle	1	0. 01**	2	0. 01**	3	0. 01**
Horizontal angle	2	0. 01**	2	0. 01**	NA	NA
Subject (gender)	28	0. 01**	28	0. 01**	28	0. 01**
Error	984		984		420	
Total	2088		2088		928	

Notes. ** highly significant ($p<0.01$)

Table 2. Duncan's multiple range tests for isometric push strength (Newtons or N)

Factor	Data set	Mean comparison			
Reach	1	Extreme	Maximum	Normal	
		95.09	84.42	66.25	
	2	Extreme	Maximum		
		88.23	78.25		
	3	Extreme	Maximum		
		93.91	86.01		
Vertical angle (degree)	1	45°	0°		
		89.19	73.61		
	2	45°	0°	-20°	
		97.99	81.93	71.45	
	3	90°	45°	0°	-20
		116.32	100.46	79.21	70.51
Horizontal angle (degree)	1	0°	90°	135°	
		92.1	81.25	70.55	
	2	0°	90°	135°	
		95.79	82.48	72.61	

Isometric Pull-down Strength

Results of ANOVA for pull-down strength were similar to those for push-up strength. Position, gender, reach, vertical and horizontal angles had highly significant effect on pull-down strength ($p<0.01$) Duncan's multiple range test showed highly significant decreases in strength as reach level increased. Similar to push-up exertion, this was probably due to the muscle length-tension effect and the mechanical advantage. As vertical angle increased, pull-down strength significantly increased. Again, the deployment of body weight is the most important factor allowing for greater strength in the overhead position. Strengths at 90° and 135° were significantly greater than that at 0° probably due to mechanical advantage.

CONCLUSIONS

In summary, the conclusions drawn from this investigation were as follows:

1. Reach level had a significant effect on strengths. As reach increased, push strength increased. Similar to push strength, pull strength in normal reach was significantly less than that in maximum and extreme reaches. Nevertheless, pull strength in maximum and extreme reach levels were not significantly different, except for the case of overhead location. Push-up and pull-down strengths mostly decreased with increasing reach levels, except for the case of the overhead location.

2. Vertical angle had a significant effect on strengths. Push, pull and pull-down strengths increased significantly as vertical angle increased. Push-up strength decreased when vertical angle changed from -20° to 0° and 45°, whereas the greatest strength was found at the overhead location.

3. Horizontal angle had a significant impact on strengths. Push and pull strengths decreased as horizontal angle increased. Push-up and pull-down strengths at 90° and 135° were significantly greater than that at 0°.

CONCLUDING REMARKS

For locating controls and equipment in workstation and task design, where muscle strengths are required, due consideration must be given to workspace reach levels, and vertical and horizontal angles. Thus, workstation layout optimization for both comfort and productivity can be achieved.

REFERENCES

Chaffin, D.B., Andres, R.O. and Garg, A. (1983) Volitional postures during maximal push/pull exertions in the sagittal plane, *Human Factors*, 25 (5), 541-550.

Jongkol, P. (2001) Measurement and evaluation of isometric and isokinetic strengths in workspace. Ph.D. Dissertation, Dalhousie University, Halifax, NS, Canada.

Mital, A. and Kumar, S., (1998) Human muscle strength definition, measurement, and usage: Part I - Guideline for the practitioner, *International Journal of Industrial Ergonomics*, 22, 101-121.