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Isometric Pull-Push Strengths in Workspace: 2. Analysis of Spatial Factors

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The effect of reach levels, horizontal angles and vertical angles on isometric pull and push strengths of males and females in standing and seated positions was determined. The effect of reach levels on strength varied as a consequence of force direction, working position and gender. Reach level has a significant effect on women's pull strength in the seated position and on push strength in the standing position. The strength value was significantly greater in the extreme reach than in maximum or normal reach. Vertical angle φ had a significant effect on strength consistently in all cases. Strength values increased significantly with the increase of φ angles from 0º to 45º to 90º. The horizontal angle θ had a significant influence only on the pull strength of standing and seated men and standing women (not seated woman). The maximum strength was significantly greater at θ = 90º.

isometric strength push and pull strengths workspace reach levels
vertical and horizontal angles workstation design

1. INTRODUCTION

Isometric strength measurement can help to determine potential strain to a worker in a given workplace situation [1]. A profile mapping maximum strength values to a person's workspace can help to plan task layout to avoid overexertion [2]. Under controlled conditions, where such a profile is defined, the roles of factors that may affect strength can be studied.

Exertion locations may be characterized relative to an individual's anthropometry using reach, and horizontal and vertical angles to define completely measurement locations. Direction can be similarly defined relative to individual anthropometry using radial pull and push exertions centered on body joint locations [3]. For both productivity and comfort, testing the statistical significance of each of these factors will help to define key variables for workstation design optimization.

The strength measurement would be affected by arm reach and trunk extension. Therefore arm reach and posture should be defined precisely [3]. Thus, normal, maximum and extreme functional reach envelopes provide a logical basis for strength measurement. The motion economy principles [4] favour the use of a normal reach envelope (within reach of the lower arm alone) to that of a maximum reach envelope (at arm extension) or that of an extreme reach envelope (with trunk extension); the significance of this relationship is less clear for strength measurement. In particular pull and push strengths generally increase with separation from the body [2], however, these spatial variations have not been documented for statistical significance employing anthropmetric reach definitions. Also, this relationship has not been studied beyond maximum reach conditions. Many tasks performed in industry require pull and push exertions. Studies have shown that

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strength changes with different combinations of vertical and horizontal angles and exertion direction [2, 5].

The main objectives of this investigation were to: (1) analyze the significance of location factors, as combinations of reach, vertical angle and horizontal angle on radial pull and push strengths in standing and seated positions among males and females, based on data collected under controlled conditions [6], and (2) perform statistical analyses (an analysis of variance [ANOVA] and Fisher's pair-wise comparison test) of strength data.

2. METHOD

To obtain data for this analysis a series of isometric strength measurements were made. The experimental method in terms of participants, strength measurement system, experimental situation and experimental procedure was described earlier [6]. Consequently, it will not be repeated here.

3. RESULTS

Experimental data were analyzed using Minitab software. Strength data were broken down into subgroups according to force direction, working position and gender. For each data set, strength profiles are presented according to workspace reach envelopes, which are described by: (1) reach level, (2) vertical angel φ, and (3) horizontal angle θ. An ANOVA was performed to evaluate the effect of the three experimental factors on strength output. When the results of the ANOVA on an individual factor were significant ($p \leq .05$), pair-wise mean comparisons were made by employing Fisher's pair-wise comparison test, which was chosen for its ability to deal with non-orthogonal data sets [7]. The comparisons in strength profiles were made to obtain a further understanding of the effect of force direction, working position and gender.

3.1. Pull Strength of Standing Men

An ANOVA of reach level for pull strength of standing men revealed that reach level had no significant effect on strength ($F = 1.62$, $p \leq .20$). However, an ANOVA showed that angle φ had a highly significant effect on strength ($F = 252.36$, $p < .01$). Fisher's test of pair-wise comparisons showed that strength values increased significantly with the increase in φ angles from 0º (103 N, mean value) to 45º (147 N) to 90º (398 N) (Table 1).

TABLE 1. Fisher's Pair-Wise Comparison in Push Strength of Standing Men on φ Angle

φ	0º	45º	90º
0º	—	43.97**	295.61**
45º		—	251.64**
90º			—

Notes. Values in order of increasing differences in mean. The minimum strength of 102.79 N at φ = 0º, **highly significant ($p < .01$), φ—vertical angle.

An ANOVA showed that horizontal angle θ had a highly significant effect on pull strength of standing men ($F = 9.05$, $p < .01$). Fisher's test revealed that θ = 90º (185 N) was significantly greater than θ angles of 0º (126 N), 135º (127 N) and 45º (134 N) (Table 2). This was due to superior exertion or performance at the overhead location (φ = 90º and θ = 90º).

TABLE 2. Fisher's Pair-Wise Comparison in Pull Strength on θ Angle

θ	0º	135º	45º	90º
0º	—	0.47	8.23	59.05**
135º			7.76	58.58**
45º				50.82**
90º				—

Notes. The minimum strength of 125.72 at θ = 0º, **highly significant ($p < .01$), θ—horizontal angle.

3. 2. Pull Strength of Standing Women

An ANOVA showed that reach level had no significant effect on pull strength of standing women ($F = 0.45$, $p < .64$). An ANOVA revealed that angle φ had a highly significant effect on strength (F = 113.47, p < .01). Fisher's test showed strength values increased significantly with the increase in φ angles from 0º (67 N) to 45º (92 N) to 90º (223 N) (Table 3).

TABLE 3. Fisher's Pair-Wise Comparison in Push Strength of Standing Women on φ Angle

φ	0º	45º	90º
0º	—	22.55**	156.12**
45º		—	130.57**
90º			—

Notes. The minimum strength of 66.61 N at φ = 0º, **highly significant (p < .01), φ—vertical angle.

An ANOVA revealed that angle θ had a highly significant effect on strength (F = 6.73, p < .01). Fisher's test showed that the highest strength value at θ = 90º (112 N) was significantly greater than strength values at θ = 135º (76 N), 45º (83 N) and 0º (86 N) (Table 4). The effects of reach level, vertical angle φ and horizontal angle θ on pull strength were found to be similar between standing men and women.

TABLE 4. Fisher's Pair-Wise Comparison in Pull Strength of Standing Women on θ Angle

θ	135º	45º	0º	90º
135º	—	6.29	9.77	35.31**
45º			3.48	29.02**
0º				25.34**
90º				—

Notes. The minimum strength of 76.36 N at θ = 135º, **highly significant (p < .01), θ—horizontal angle.

3.3. Pull Strength of Seated Men

An ANOVA showed that reach level had no significant effect on pull strength of seated men (F = 1.73, p < .18). The ANOVA revealed that the effect of angle φ on strength was highly significant (F = 49.61, p < .01). Fisher's test showed that strength values increased significantly as φ angles increased from 0º (199 N) to 45º (232 N) to 90º (364 N) (Table 5).

TABLE 5. Fisher's Pair-Wise Comparison in Pull Strength of Seated Men on φ Angle

φ	0º	45º	90º
0º	—	33.01**	164.95**
45º		—	131.94**
90º			—

Notes. The minimum strength of 198.94 N at φ = 0º, **highly significant (p < .01), φ—vertical angle.

The ANOVA showed that θ angle had a highly significant effect on strength (F = 5.04, p < .01). Fisher's test revealed that the strength at θ = 90º (248 N) was significantly greater than strengths at 135º (201 N), 0º (221 N) and 45º (232 N) (Table 6). A significant difference was also found between θ angles 135º and 45º. Strength was consistently the strongest at the overhead location as observed earlier.

TABLE 6. Fisher's Pair-Wise Comparison in Pull Strength of Standing Women on θ Angle

θ	135º	0º	45º	90º
135º	—	19.87	30.67**	46.82**
0º			10.80	26.95**
45º				16.15
90º				—

Notes. The minimum strength of 201.33 N at θ = 135º, **highly significant (p < .01), θ—horizontal angle.

3.4. Pull Strength of Seated Women

An ANOVA showed that reach level had a highly significant effect on pull strength of seated women (F = 4.87, p < .01). Fisher's test revealed that strength exertion in the extreme reach (137 N) was significantly greater that at normal (103 N) and maximum (116 N) reach (Table 7).

TABLE 7. Fisher's Pair-Wise Comparison in Push Strength of Standing Women on Reach Level

Reach	Normal	Maximum	Extreme
Normal	—	13.05	33.98**
Maximum		—	20.93**
Extreme			—

Notes. The minimum strength of 102.87 N in the maximum reach envelope, **highly significant (p < .01).

The ANOVA showed that the φ angle had a highly significant effect on strength ($F = 11.30$, $p < .01$). Fisher's test revealed that pulling exertion at the overhead location, φ = 90º (190 N), was significantly advantageous over pulling exertion at φ = 0º (106 N) and 45º (122 N) (Table 8).

TABLE 8. Fisher's Pair-Wise Comparison in Pull Strength of Seated Women on φ Angle

φ	0º	45º	90º
0º	—	16.32	84.45**
45º		—	68.14**
90º			—

Notes. The minimum strength of 105.99 N at φ = 0º, **highly significant ($p < .01$), φ—vertical angle.

The ANOVA revealed that the θ angle had no significant effect on strength ($F = 2.54$, $p < .06$). The results closely missed the significance level.

Reach level significantly affected women's pull strength in the seated position but such strength had no effect for men. The θ angle significantly affected men's pull strength in the seated position but not the corresponding strength for women. However, both seated men's and women's pull strength significantly increased with the increase in φ angles.

3.5. Push Strength of Standing Men

An ANOVA showed that reach level had no significant effect on push strength of standing men ($F = 2.56$, $p < .88$). The ANOVA revealed that the φ angle had a highly significant effect on strength ($F = 22.06$, $p < .01$). Fisher's test showed that strength values increased significantly as φ angles increased from 0º (104 N) to 45º (131 N) to 90º (181 N) (Table 9).

TABLE 9. Fisher's Pair-Wise Comparison in Push Strength of Standing Men on φ Angle

φ	0º	45º	90º
0º	—	26.88**	78.61**
45º		—	51.73**
90º			—

Notes. The minimum strength of 103.76 N at φ = 0º, **highly significant ($p < .01$), φ—vertical angle.

The ANOVA revealed that θ angle had no significant effect on strength ($F = 2.38$, $p < .07$).

3.6. Push Strength of Standing Women

An ANOVA revealed that reach level had a highly significant effect on push strength of standing women ($F = 19.76$, $p < .01$). Fisher's test showed that strength exertion at extreme reach (103 N) was significantly greater than at normal (74 N) and maximum (73 N) reach (Table 10).

TABLE 10. Fisher's Pair-Wise Comparison in Push Strength of Standing Women on Reach Level

Reach	Maximum	Normal	Extreme
Maximum	—	1.15	29.54**
Normal		—	28.39**
Extreme			—

Notes. The minimum strength of 73.14 N in the maximum reach envelope, **highly significant ($p < .01$).

The ANOVA showed that the φ angle had a highly significant on strength ($F = 9.70$, $p < .01$). Fisher's test revealed that in the overhead location, φ = 90º (119 N), strength generation was significantly higher than at φ = 0º (74 N) and 45º (89 N) (Table 11).

TABLE 11. Fisher's Pair-Wise Comparison in Push Strength of Standing Women on φ Angle

φ	0º	45º	90º
0º	—	14.93**	45.61**
45º		—	30.68**
90º			—

Notes. The minimum strength of 73.86 N at φ = 0º, **highly significant ($p < .01$), φ—vertical angle.

The ANOVA revealed that the θ angle had no significant effect on strength ($F = .58$, $p < .63$).

The effect of reach level was significant in terms of women's strength performance but not in the case of men. The effects of φ angle and θ angle were basically the same for men and women, in statistical terms.

3.7. Push Strength of Seated Men

An ANOVA showed that reach level had no significant effect on push strength of seated men ($F = 0.42, p < .66$). The ANOVA revealed that the φ angle had a highly significant effect on strength ($F = 12.19, p < .01$). Fisher's test showed that strength at 90º (200 N) was significantly greater than at φ = 0º (130 N) to 45º (138 N) (Table 12).

TABLE 12. Fisher's Pair-Wise Comparison in Push Strength of Seated Men on φ Angle

φ	0º	45º	90º
0º	—	8.13	70.79**
45º		—	62.66**
90º			—

Notes. The minimum strength of 129.63 N at φ = 0º, **highly significant ($p < .01$), φ—vertical angle.

The ANOVA revealed that the θ angle had no significant effect on strength ($F = 2.47, p < .06$).

3.8. Push Strength of Seated Women

An ANOVA showed that reach level had no significant effect on push strength of seated women ($F = 0.73, p < .48$). The ANOVA revealed that the φ angle had a highly significant effect on strength ($F = 4.35, p < .01$). Fisher's test showed that strength at φ = 90º (85 N) was significantly greater than φ at 0º (62 N) or 45º (68 N) (Table 13).

TABLE 13. Fisher's Pair-Wise Comparison in Push Strength of Seated Men on φ Angle

φ	0º	45º	90º
0º	—	5.79	22.99**
45º		—	17.20**
90º			—

Notes. The minimum strength of 62.03 N at φ = 0º, **highly significant ($p < .01$), φ—vertical angle.

The ANOVA revealed that strength effect of the θ angle was not significant ($F = 0.71, p < .55$). The effects of reach level, angle φ and angle θ were similar for men and women.

4. DISCUSSION

Earlier [6] it was pointed out that only Hunsicker's [2] study of arm strength of seated males, in relation to different degrees of elbow flexion comes somewhat close to representing anthropometrically determined reach space envelopes. Pull and push movements are noticeably influenced by the angle of the elbow. Maximum strengths of the 5th percentile male were 245 N for pull at 150º and 223 N for push at 180º. In addition to inherent strength attributes, the pattern of a person's strength profiles are strongly influenced by the consequence of the mechanical advantages of such movements. This is due to the angles involved and the effects of muscle contractions in applying leverage to body members.

In this study, the pull strength of standing men had no significant effect on reach level. Stated otherwise, pull strength did not increase significantly with increased reach level. However, Davis and Stubbs [5] found that pull strength increased with the increase in reach distance.

The pull strength of standing men (in this study) at the horizontal angle θ = 90º (185 N) was significantly greater than all other θ angles (0º, 45º and 135º). Similar results were also found for the pulling strength of standing females and seated males. This may be partly due to the superior strength at φ = 90º (390 N) test location, which was only tested at θ = 90º. Davis and Stubbs (1977) found that the saggital plane in front of the active shoulder corresponds to the most natural muscular length for extensor and flexor muscles around the shoulder and this could contribute to the superior strength at this location.

The pull and push strengths of standing and seated men and women were found to be significantly higher at the vertical angle φ = 90º (overhead location) than at φ = 45º or 0º. Garg and Beller [8] found that the optimum pulling appears to be at 25º, compared to 15 and 35º from the horizontal plane.

5. CONCLUSIONS

In summary, the conclusions reached from this investigation were:

1. Reach levels affected strength as a consequence of force direction, working position and gender. Reach level significantly affected women's pull strength in the seated position and push strength in the standing position. The strength value was significantly greater in the extreme reach than maximum or normal reach. In other cases, the effect of reach level was not significant.
2. Vertical angle φ significantly affected pull and push strengths of standing and seated men and women in a consistent manner. As the φ angle increased from the table surface ($\varphi = 0^o$) to 45º to 90º or overhead location, the strength values increased significantly in all the cases.
3. Horizontal angle θ had a significant effect on the pull strength of standing and seated men and standing women but not seated women. The pull strength was significantly greater at $\theta = 90^o$ than at $\theta = 0^o$, 45º and 135º. The θ angle had no significant effect on the push strength.

6. CONCLUDING REMARKS

For locating controls and handles in a workstation design for standing and seated men and women, where pull and push forces or exertions are required, due consideration must be given to reach levels, and vertical and horizontal angles in the workspace. Thus, workstation layout optimization for both productivity and comfort can be achieved.

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