THE EFFECT OF HANDLE FRICTION AND TORQUE ON AXIAL PUSH FORCE

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INTRODUCTION

Insufficient hand-handle friction can limit coupling between the hand and handle, thus reducing maximum axial push force on a handle that a person can exert or increasing required grip force to complete a given axial push task. Previous studies investigated push force without friction constraints only, e.g., pushing against a wall (Chaffin et al., 1983; Daams, 1993; Peebles and Norris, 2003).

It has been demonstrated that when the hand applies torque about the long axis of a cylindrical object in a power grip, inward torque (in the direction fingertips point) resulted in increased normal force on the fingertips and thus greater maximum torque, compared to outward torque (in the direction the thumb points) (Seo and Armstrong, 2006). Based on this finding, it can be expected that increased grip force from inward torque would result in increased axial push force on a cylindrical handle.

This study tested 2 hypotheses: 1) Maximum axial push force is related to handle friction. 2) Subjects voluntarily apply inward torque to increase grip force and axial push force.

METHODS

Twelve healthy right-handed university students (6 males, 6 females, age=21-35 yrs) grasped a horizontal cylindrical handle with their right hand and performed isometric maximum axial push force exertions along the long axis of a cylindrical handle for 5 sec, in a standing posture. The handle was adjusted to each subject's elbow height. Subjects were allowed to freely choose a posture, e.g., lean forward.

Dependent variables were maximum axial push force, torque and grip force. Independent variables were handle friction (low friction aluminum vs. high friction rubber) and push method (straight vs. preferred). For the straight method, subjects were instructed to exert only axial push force with no torque about the long axis of the handle. For the preferred method, no specific instruction was given but to exert the maximum axial push force. Each condition was presented twice to subjects in a random order. A two-minute break was given between successive trials.

Grip force was measured by a split cylinder (Edgren et al., 2004) which was covered with a smooth 3.5 mm-thick rubber sheet, or smooth 0.2 mm-thick aluminum sheet. With the sheet of rubber or aluminum, the tested handle diameters were 57.8 and 51.2 mm for the rubber and aluminum, respectively. Via universal joints, the handle was connected to a load cell that measured axial push force and torque. Data were averaged over 2 sec during maximum exertions.

RESULTS AND DISCUSSION

Hypothesis 1: The data support the first hypothesis. Maximum axial push force was 10% greater for the high friction rubber handle than for low friction aluminum handle (see Table 1, $p<0.01$), although grip force was not different between the two handle materials (see Table 1, $p>0.05$). Maximum axial push force measured in this

Table 1: Max axial push force, grip force and inward torque for the two methods, handle materials and gender (mean ± SD)

Method	Push (N)	Grip (N)	Torque (Nm)
Male (n=6), aluminum handle			
Prefer	123 ±11	143 ±78	1.9 ±1.8
Straight	119 ±12	109 ±51	0.7 ±0.5
Male (n=6), rubber handle			
Prefer	137 ±26	121 ±51	1.1 ±2.1
Straight	130 ±18	115 ±50	0.3 ±0.6
Female (n=6), aluminum handle			
Prefer	62 ±21	56 ±24	0.5 ±0.5
Straight	59 ±23	51 ±19	0.2 ±0.2
Female (n=6), rubber handle			
Prefer	64 ±26	45 ±19	0.6 ±1.1
Straight	61 ±29	39 ±35	0.1 ±0.1

study is about the half of push strength in the absence of friction constraints (Chaffin et al., 1983; Daams, 1993; Peebles and Norris, 2003). It suggests that the weakest link in the chain was the friction between the hand and handle in this study.

Axial push force may also have been limited by wrist strength. The reaction force from push generates a moment about the wrist joint in the ulnar direction, requiring radial deviators' activities for stabilizing the wrist. The voluntary wrist abduction strength reported by Delp et al. (1996) is only 7% greater than the maximum axial push force measured in this study, suggesting that wrist strength may have been the limiting factor; however, when the wrist becomes deviated in the ulnar direction more with pushing, the passive force of the wrist will increase and the wrist may not limit axial push. Also, a fixed handle (with no universal joints) may increase axial push force, as subjects can apply downward force to the handle: The reaction force from downward push can counterbalance the moment about the wrist joint produced by the reaction force from an axial push exertion.

Hypothesis 2: The data support the hypothesis that subjects voluntarily apply inward torque during maximum axial push force exertions (see Table 1, $p<0.01$). This voluntary inward torque appears to increase grip force and thus axial push force 7%, compared to the straight method (see Table 1, $p<0.01$). Within the preferred method, high axial push force was associated with high grip force and high inward torque ($p<0.01$), as predicted based on our previous study (Seo and Armstrong, 2006).

CONCLUSIONS

- Higher axial push force can be produced with higher handle friction by a worker of a given strength.
- Design of work objects or consumer products should assume that workers or users use inward torque to increase grip force and thus axial push force.

REFERENCES

Chaffin, D.B. et al. (1983). *Human Factors*, **25**, 541-550.

Daams, B. J. (1993). *Ergonomics*, **36**, 397-406.

Delp, S.L. et al. (1996). *Journal of Biomechanics*, **29** (10) 1371-1375.

Edgren, C. S. et al. (2004). *Human Factors*, **46** (2) 2 44-251.

Peebles, L., Norris, B. (2003). *Applied Ergonomics*, **34**, 73-88.

Seo, N., Armstrong, T. J. (2006). *ASB 30th meeting, Blacksburg, VA.*

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