Finger Pinch Loosening and Tightening Torques on Small Cylindrical Handles Among Industrial Workers

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Abstract: Ten male and 13 female assembly line manufacturing workers exerted MVC torques on small (smooth and knurled) cylindrical handles of diameters 3.3, 5.0, 6.4, 9.5, and 19.0 mm. Three other handles with flanged finger contact were also tested to simulate torqueing on a specific medical device. The flange widths were 6.4, 9.5, and 19.0 mm (6 mm high). Both loosening and tightening exertions were tested. Each subject performed 26 different torque exertions. The results indicated that finger torque strength decreased steadily with diameter of the cylindrical handle, or with the width of the flange. Torque was also stronger for tightening compared to loosening, and for knurled cylinders compared with smooth ones. There were 2-factor interaction effects on torque – surface*direction, surface*diameter and diameter*direction for the cylinders; and direction*width for the flanges, indicating that the change in torque over one factor is not independent of all other factors.

Keywords: Torque, cylinders, flange

1. Introduction

The type of grip used for holding, squeezing, or torqueing, and the maximum muscular force or torque that can be generated, depend on the size and nature of the handle in contact with the hand, among other factors. When exerting torques on handles of a circular cross-section (lids, knobs or screws) the intent is almost exclusively to tighten or loosen it onto or from some object to which it is coupled. In some cases, as in mechanical systems, the loosening or tightening torque may be achieved by using a hand tool (e.g. a wrench). However, the human hand may also be used for generating torques without a tool. The hand may be used for tightening during the initial stages of torqueing or during the final stages of loosening. The type of hand grip used for torqueing depends on the size of the handle and the amount of force intended. Other factors, such as the orientation or position of the handle with respect to the subject's height and position are also influential. Most studies on hand torqueing strength have concentrated on large handles using the power grip, or some variation of it, in which the object or handle is held partly or wholly within the palm of the hand. Examples of these handles include cylinders (Imrhan and Jenkins, 1998; Imrhan and Farahmand, 1998) and jar lids (Rohles et al., 1983; and Imrhan and Loo, 1988). However, people are often required to grip and turn small objects, using pinch grips.

The need to turn things with our fingers is important where the object is too small to be gripped within the palm of the hand, or where the use of tools is inappropriate. Space for the manipulation of tools may be limited, or it may be difficult to grasp the object with available tools, as in motor vehicle repair and maintenance. In some cases, as in the manufacturing and use of medical devices, care must be taken not to damage a product by using a hand tool. This may be achieved by gripping and turning with the fingers. Other examples are the constant handling of screws to be placed in a certain positions in automated machines for the latter to work properly, and loosening and tightening small screws for assembly rework of products. Repetitiveness, large finger forces, and a bent wrist during these tasks are likely to lead to cumulative trauma disorders related to mechanical strains in the musculo-tendinous units of the hand (Kroemer et al., 1994). The small areas on which finger forces are applied may also lead to very high contact pressures. It is important, therefore, to know the strength capabilities of the fingers for torqueing and to understand the nature of this kind of torqueing in relation to the handles or other contact surfaces. Available published data for finger torqueing strength are inadequate for guiding designers of instruments, other consumer devices (medical aids), or work tasks. The study of Adams and Peterson (1988) and Swain et al. (1970), with knobs and electrical connectors, are exceptions. In addition, data using industrial workers, who may be involved in such work tasks, are rare. The present study aims to expand the finger torqueing data base and enhance the understanding of small-handle torqueing, using industrial assembly line workers, in a controlled experiment. A short preliminary analysis of the incomplete data in this study, was presented earlier at a conference (Imrhan et al., 2005). To the authors' knowledge, no other data on finger torqueing has since been published. In this study, finger torque strengths were tested while gripping the surface of (i) small cylinders and (ii) a flange on handles with a small base. The objectives were to determine the effects of diameter, surface finish, direction of torqueing, and type of handle on finger torqueing strength.

2. Methods

2.1 Subjects

A sample of twenty three industrial workers, 10 males and 13 females, between the ages of 22 and 55 years participated in this study as subjects. All worked on an electronics assembly line and were of various ethnic backgrounds. All, except two males, were right handed. All torqueing were done with the right hand. Informed consent was obtained in the standard manner dictated by to the university's human subjects review process. Summary data are shown in Table 1.

Table 1. Summary table of subjects' characteristics

Variable	Mean	Standard Deviation	Range
Age (yr)	42.8 (female, n=13) 32.7 (male, n=10)	10.1 10.5	22.0-55.1 22.4-49.4
Height (cm)	156.5 176.6	9.1 8.1	165.1-188.0 132.1-170.2
Weight (kgf)	63.5 80.7	12.1 22.3	43.1-82.3 56.8-129.1
Handgrip Strength (kgf)	27.9 48.1	5.5 8.1	18.9-38.0 37.5-63.8

2.2 Apparatus and Testing Procedures

Peak MVC torque was measured using a portable 'Dillon' torque transducer with a 8475 in-oz (or 60 N-m) capacity. The transducer was connected to a torque indicator, with a digital readout, in which the maximum torque could be 'held' for retrieval. The shaft of the transducer was fitted with an adaptor into which small torqueing handles were snugly fitted. There were three different types of handles – smooth and knurled aluminum cylinders, and cylinders with flanges that can be gripped with the tips of fingers (Figure 1). The smooth and knurled cylinders were of five different diameters – 3.3, 5.0, 6.4, and 9.5 and 19.0 mm. All were 18 mm thick. The flanges on the other handles were of lengths 6.4, 9.5, and 19.0 mm and height, 7.5mm. This was approximately the same height as a medical device sample used for designing the flanged aluminum handles (Figure 1).

The torque transducer was placed on a work table of approximately 32 inches (81 cm) high during measurements (Figure 2), so that the handle was 39 inches (99 cm) above the floor. Subjects stood and rested their left hand on a wooden base attached to the transducer housing, and gripped and exerted torques with the other hand (Figure 2). They exerted MVC torques according to standard methods of MVC strength generation (Kroemer, 1994). Each measurement was taken twice, at random. If the two replications were not within 15% of each other, the measurement was repeated. The larger of the two valid measurements was used for data analysis. Both tightening (clockwise) and loosening (counterclockwise) torques were measured at each diameter for the smooth and knurled cylinder surfaces, and for the flanged handles. For each person the measurements were randomized. Subjects were tested in groups of 2 to 3 to achieve resting times of at least 2 minutes to minimize or eliminate fatigue effects. Precautions were taken to prevent data contamination due to external influences – noise or other disturbances, feedback, motivation, etc. (Kroemer et al., 1994).

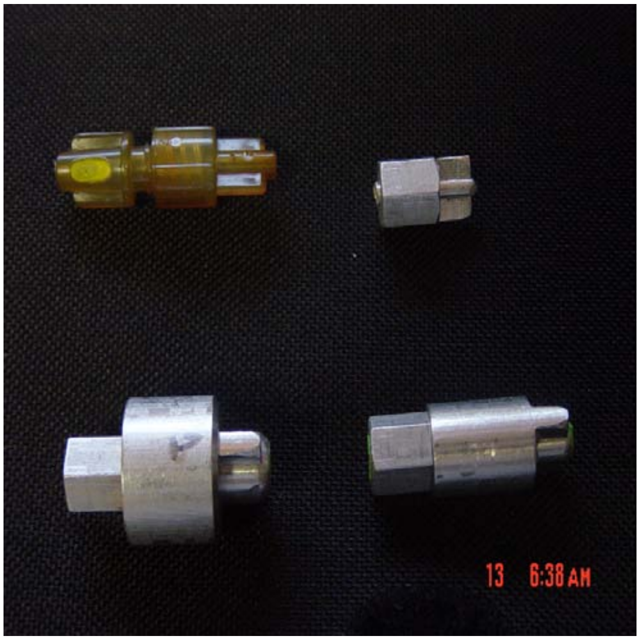

Figure 1. Flanged handles – bottom left, 6.4 mm; bottom right, (5.0 mm); top right (3.3 mm); top left (from medical device)

Figure 2. Torqueing posture

3. Results and Discussion

3.1.Analysis of Cylindrical Handles

For both males and females, torque decreased steadily with decreasing diameter, regardless of the type of grip surface or direction of exertion (Tables 2 and 3). On the average, over all diameters, females were 72% as strong as males, the ratio being fairly consistent across diameters (69-74%). Because the male and female data were so very different in magnitudes, under all testing conditions (factor level combinations), they were analyzed separately.

Table 2. Summary statistics (mean and standard deviation) of torques, in inch-ounce (in-oz), at each combination of diameter, surface finish (smooth, knurled or flanged) and direction of exertion (loosening or tightening) in males (n=10).

	Smooth cylinder		Knurled cylinder		Flanged cylinder	
Diameter inch (mm)	Loosening13	Tightening12	Loosening	Tightening	Loosening	Tightening
0.76 (19.0)	Mean=114.2 s.d.= (28.3)	112.1 (23.3)	138.3 (16.9)	130.3 (18.3)	94.5 (20.54)	108.7 (16.1)
0.375 (9.5)	56.4 (16.2)	61.4 (12.2)	86.2 (22.1)	95.5 (17.2)	67.1 (13.11)	73.7 (18.08)
0.25 (6.4)	33.3 (8.6)	36.6 (17.2)	54.8 (8.2)	67.2 (8.7)	49.4 (8.85)	51.2 (17.81)
0.20 (5.0)	21.9 (9.0)	22.2 (4.9)	26.0 (6.7)	41.6 (10.3)		.
0.13 (3.3)	14.2 (5.7)	16.2 (5.17)	21.2 (6.7)	28.8 (5.8)		.

Table 3. Summary statistics (mean and standard deviation) for torques, in inch-ounce (in-oz), at each combination of diameter, surface finish (smooth, knurled or flanged) and direction of exertion (loosening or tightening) in females (n=13).

	Smooth cylinder		Knurled cylinder		Flanged cylinder	
Diameter inch (mm)	Loosening13	Tightening12	Loosening	Tightening	Loosening	Tightening
0.76 (19.0)	Mean=65.8 s.d.=(19.5)	72.5 (19.1)	106.1 (33.4)	105.7 (19.4)	57.77 (16.07)	72.08 (18.26)
0.375 (9.5)	33.1 (8.8)	45.7 (18.5)	65.1 (19.1)	80.9 (18.5)	38.61 (13.33)	47.77 (15.76)
0.25 (6.4)	20.7 (6.4)	27.4 (11.3)	44.0 (15.3)	59.6 (15.6)	29.61 (9.73)	30.69 (9.20)
0.20 (5.0)	12.7 (6.0)	13.6 (5.2)	22.1 (6.8)	32.8 (11.6)	.	.
0.12 (3.3)	10.5 (4.8)	9.8 (3.1)	18.2 (6.8)	21.8 (5.6)	.	.

For both males and females, the greatest average torque was obtained for the largest diameter on the knurled surface (138.3 in-oz in males and 106.1 in-oz in females). The smallest average was obtained for the smallest diameter on the smooth surface (14.2 in-oz in males and 9.8, in females). These torques translate into greatest/smallest torque ratios of 9.7 (male) and 10.8 (female). Other studies have established torque-diameter relationships for different conditions.

Swain et al. (1970) and Adams and Peterson (1988) used small cylindrical knobs with finger grips; Rohles et al. (1983), Pheasant (1986), Shih and Wang (1996), Habes and Grant (1997), and Imrhan and Jenkins (1998, and Imrhan and Farahmand (1998) used cylindrical or cylindroid handles with power grips, and Imrhan and Loo (1998) used jar lid discs with the disc grip. ANOVA was performed on the torques to determine which factors or factor combinations were significant. The male and female data were analyzed separately. A 5x2x2 fully crossed factorial design was used, with 10 subjects per factor combination in males and 13 in females. Diameter (5), surface condition (2) and direction of torqueing (2) were fixed factors. For generalizability of the results, subject was treated as a random factor, even though the 10 males and 13 females were not selected in a truly random manner.

3.1.1 Main Effects in ANOVA

The ANOVA results confirmed that all three main factors -- diameter (p<.001), surface finish (p<.0001), and direction of torque (p<.03) -- affected MVC peak torque significantly, in both males and females. There were a few significant 2-factor interactions also. These are explained later. Whilst the interpretation of significant 2-way interactions (discussed below) is more important than the significant main effects, the significance of the latter was extremely high (p<0.0001) and, therefore, warrants a separate interpretation from the interaction effects:

(a) *Direction main effect* – Loosening was weaker than tightening. For females loosening torque was 84.8% as strong as tightening torque (40.3 vs. 47.7 in-oz, or 0.285 vs. 0.333 N-m). For males it was 71% (59.8 vs. 65.3 in-oz or 0.423 vs. 0.462 N-m). By contrast, Adams and Peterson (1988)found a smaller difference -- loosening torques were approximately 98% as strong as tightening ones, for either sex. The difference in the two studies is probably due to the orientation of the forearm while torqueing. The orientations of the handles in the two studies were not the same. In the present study, loosening required a combination of pronation of the forearm and radial deviation of the wrist; and tightening required supination of the forearm and ulnar deviation of the wrist.

(b) S*urface finish main effect*– The knurls provided greater frictional resistance with the hand and accounted for greater torques. For females, the smooth/knurled torque ratio was 56% (31.2 vs. 55.6 in-oz or 0.221 vs. 0.394 N-m). For males, it was 70% (48.8 vs. 69.3 in-oz or 0.345 vs. 0.491 N-m).

(c) D*iameter main effect*– There was a steady increase in torque as diameter increased, in both sexes (Tables 2 and 3). For example, knurled-handle torques increased from 20.0 in-oz to 105.9 in-oz in females, and from 26.9 to 134.2 in-oz in males (or 0.14-0.75 N-m in females, and 0.19-0.95 N-m in males). The female/male torque ratios across diameters in the present study were fairly consistent, ranging from 0.71-0.79, with an average of 0.74. Tukey's multiple comparison test confirmed that the torques at the two smallest diameters were not significantly different from one another (p>0.05), but were weaker than the torques at the three largest diameters (p<0.01). Also, the torques at the three largest diameters were significantly different from each other (p<0.01). Swain et al (1970) investigated small cylindrical handle diameters (9.5, 12.7, and19.0 mm) and also found finger grip torques to increase steadily with diameter. However, their torque magnitudes were greater, due to different torqueing conditions. For 5th -95th percentile males, they were 44-120, 56-150 and 90-250 in-oz. Adams and Peterson (1988) also found torque to increase steadily as diameter increased. They used larger diameters and wrap around grasps with greater finger-handle contact area with the thumb and index finger (lateral pinch mode). Imrhan and Loo (1988) also found a monotonic increasing torque-diameter trend for knurled circular jar lids. However, the trend was different for smooth lids – torque increased between 31-74 mm and decreased sharply for the 113 mm lid. It seemed that the decrease in leverage of the fingers while grasping large handles had a more pronounced effect than the increase in diameter. This does not occur for small diameter, with finger grips.

3.1.2 Interaction Effects

For the female data, there were two significant 2-factor interactions:

(i) Surface-Diameter interaction (p<0.0001) – this indicates that the difference in torque between the smooth and knurled handles was not the same at all diameters. The difference was larger for the three largest diameters (19.0, 9.5 and 6.4 mm) than for the two smallest ones (5.0 and 3.3 mm) (Figure 3). The differences amounted to 37.7, 33.6 and 27.1 in-oz (or 0.267, 0.238 and 0.192 N-m), respectively, for the three largest diameters; and 14.3 and 9.8 in-oz (0.101 and 0.069 N-m), respectively, for the two smallest ones. Imrhan and Loo (1988) also found a sharp surface-diameter interaction, with a larger torque difference at the largest diameter.

(ii) Direction-Diameter interaction (p=0.0256) – this indicates that difference between tightening and loosening torques was not the same at all diameters. The difference was larger for the two medium size diameters (9.5 and 6.4 mm) than for the more extreme ones (19.0, 5.0 and 3.3 mm) (Figure 4). For the medium diameters, the differences were14.2 and 11.1 in-oz, respectively (or 0.101 and 0.079 N-m). For the other diameters, the differences were and 3.1, 5.8 and 1.3 in-oz, respectively (0.022, 0.041, and 0.009 N-m) (Figure 4).

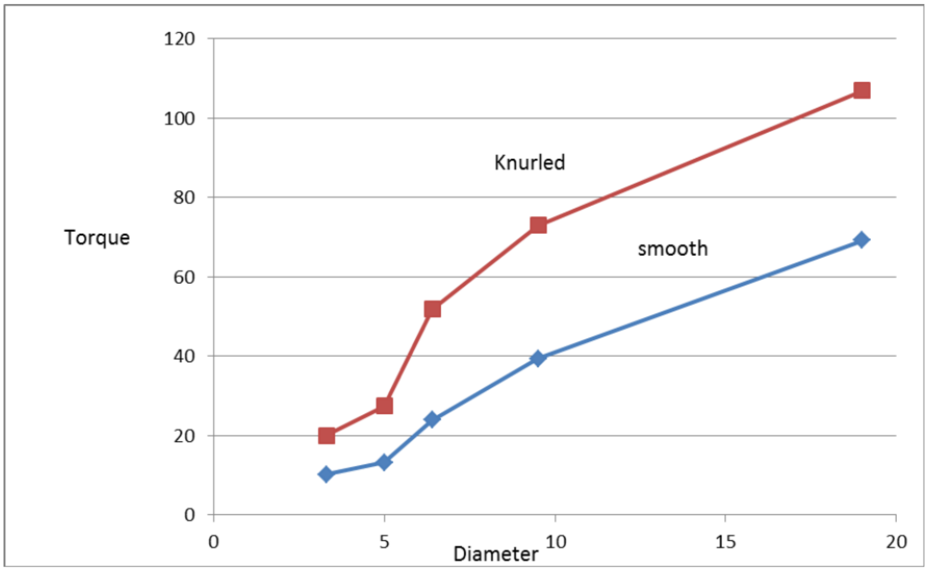

Figure 3. Interaction effect between surface condition and diameter (mm) in males on torque (in-oz)

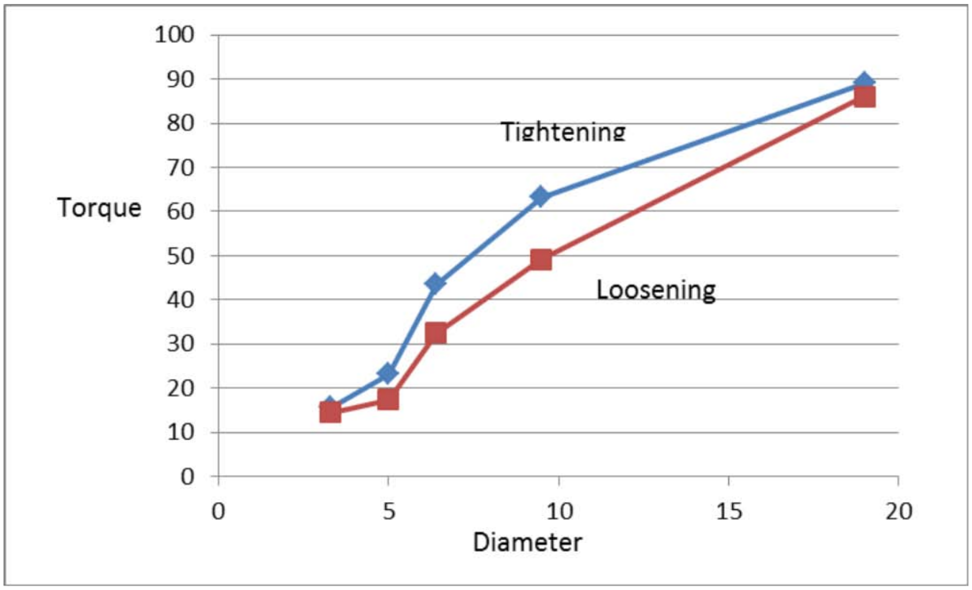

Figure 4. Interaction effect between surface condition and diameter (mm) in females on torque (in- oz)

For the male data, there was only one significant 2-factor interaction: Surface-Diameter (p=0.0004). The difference was larger for the three largest diameters (19.0, 9.5 and 6.4 mm) and smaller for the two smallest ones (5.0 and 3.3 mm). The differences amounted to 21.0, 31.7 and 26.0 in-oz (or 0.149, 0.224 and 0.184 N-m), respectively, for the larger diameters; and 11.8 and 11.7 in-oz (0.084 and 0.007 N-m), respectively, for the smallest diameters. A direction-diameter interaction was also evident but it was not statistically significant (p=.0592).

3.1.3.Tangential Finger Gripping Forces

Finger gripping forces during torqueing were estimated by using the product: Torque=Tangential force due to hand gripping (T) x Diameter of cylinder (D) (Pheasant and O'Neill, 1975; Replogle, 1983; Imrhan and Loo, 1988; and Shih and Wang, 1996). The tangential forces proved to be smaller at the more extreme diameters for both males and females, but it is not clear why this is so. While finger pinching leverage may be a negative factor for the two smallest diameters, it should not act negatively for the largest diameter (19.0 mm). In males, the tangential forces ranged from 48.1-67.7 N for the knurled surfaces and 32.3-44.1 N for the smooth surfaces. In females, they ranged from 38.2-56.8 N and 18.6-29.4 N, respectively. Imrhan and Loo (1988) also found unequal tangential forces across jar lid diameters, with the largest diameter (113 mm) yielding much smaller forces than the 31-74 mm ones. The forces that are generated from gripping during maximal torqueing are not necessarily the maximum gripping (or pinching) capabilities of the subjects, since it is not necessary to squeeze maximally on a handle to generate maximal torques. Rather, they are what subjects used for maintaining a stable grip on the handles while torqueing maximally.

3.1.4. Correlation Analysis

Torque was negatively correlated with age and positively correlated with handgrip strength, stature, and body weight (p<0.001) in this sample of subjects. Correlations ranged from 0.38-0.63 for handgrip, 0.61-0.66 for stature, 0.66-0.68 for body weight, and -0.51 to -0.56 for age.

3.2 Analysis of the Flanged Handles

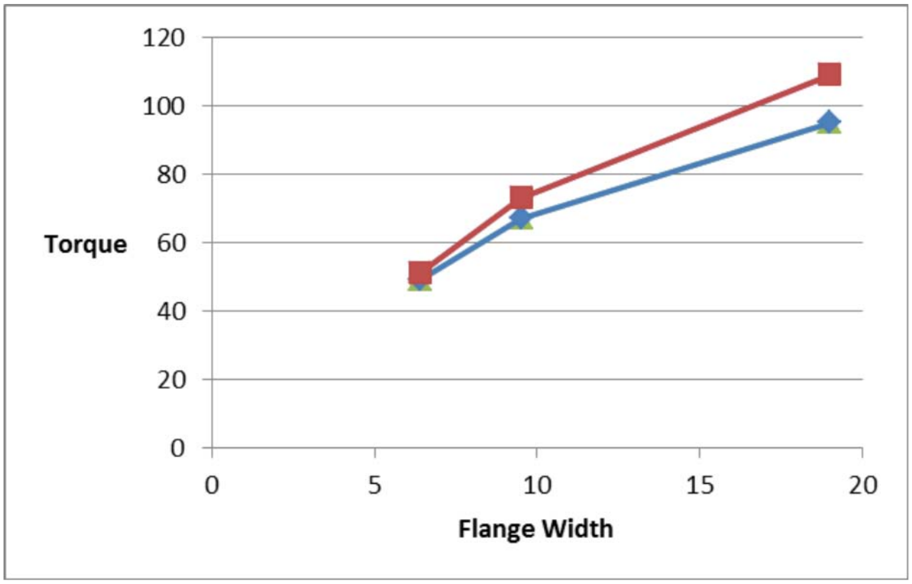

Figure 5. Interaction effect between flange width (mm) and torqueing direction in females on torque (in-oz)

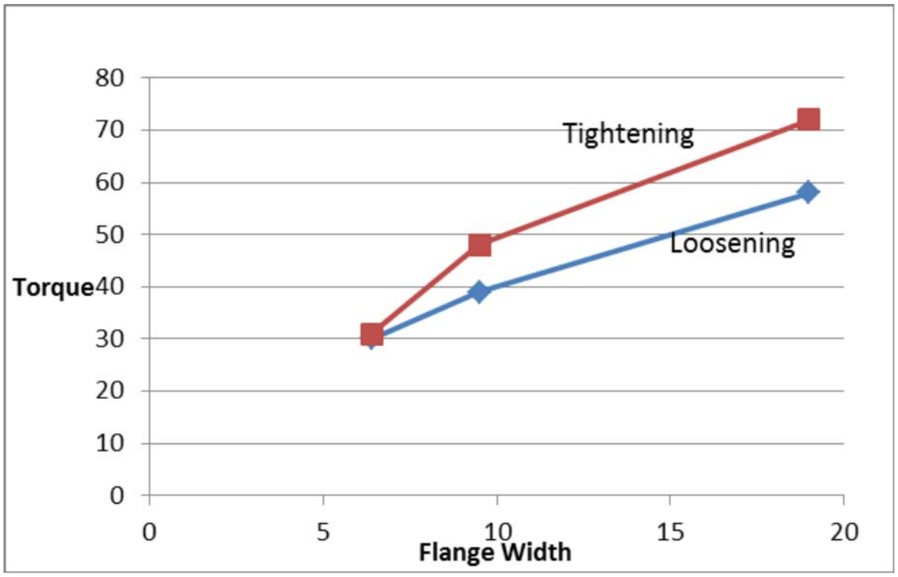

Figure 6. Interaction effect between flange width (mm) and torqueing direction in males on torque (in-oz)

Flanged cylinder torques decreased steadily as the width of the flange (and, hence, finger contact surface) decreased with each of the three torques (at 6.4, 9.5, and 19.0 mm flange width) being statistically significant from the others (Tukey's test; $p<0.05$). Average values, across subjects, ranged from 101.7 to 50.2 in-oz (or 0.720 to 0.355 N-m) in males ($p<0.01$), and 64.9-30.1 in-oz (or 0.459-0.213 N-m) in females. ANOVA indicated that both direction of torqueing and flange width were significantly related to torque strength ($p<0.001$). There was also a significant Direction*Width interaction ($p<0.03$) for both males and females; (Figures 5 and 6) ; that is, the torque difference between loosening and tightening directions depended on the width of the flange. For both sexes, the difference between tightening and loosening was smaller for the smallest width than for the two larger widths. Flanges smaller than 6.4 mm in width could not be gripped with the fingers to generate torque properly.

4. Conclusions

This experiment provides new data for MVC torques on small handles that can only be gripped with pinch grips. Some of the relationships between torques and torqueing conditions are similar to those found for large handles, but there are some salient differences. Within the range of diameters investigated this experiment, there is no optimum for torque generation. Maximal torques on small handles using pinch grips depend on more than one factor. Though the most researched factor in torqueing, diameter, proved to be the most influential, other factors were also significant. Surface finish of the contact surface and direction of torqueing proved to be important in this experiment, but other factors not investigated may also be important; e.g. depth or shape of the handle, orientation of the handle, or distance of the handle from the person. The torque magnitudes in this study are from an industrial sample of workers and are a fairly good indication of the capabilities of industrial workers, even though the sample was not very large, nor was it necessarily representative with with respect to age, physical fitness level, work experience, and other factors. Further testing would put these results in a context with a more reliable interpretation.

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