

Evaluation of handles in a maximum screwdriving torque task

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Abstract

The effects of screwdriver handle shapes (longitudinal cross-sectional shapes: circular, hexagonal, triangular; lateral cross-sectional shapes: cylindrical, double frustum, reversed double frustum, cone), surfaces (rubber, plastic), and orientations of work piece (vertical, horizontal) on torque performance, finger force and subjective discomfort were tested in a maximum screw tightening exertion. The average of finger force contributions to the total torque force were 28.1%, 39.3%, 26.5%, 6.2% in order from index to little fingers; the average of phalangeal force contributions were 47.3%, 14.0%, 20.5% and 18.1% for distal, middle, proximal and metacarpal phalanges, respectively. The plastic surface handles exhibited higher discomfort and 15% lesser torque output than the rubber coated surface handles. Analysis of handle shapes indicated that screwdrivers designed with circular or hexagonal longitudinal cross-sectional shape result in less discomfort, as well as greater torque outputs, with less finger force. In the lateral cross-sectional shapes, reversed double frustum handles were associated with the greatest reported discomfort and less torque output than the double frustum and cone handles. In conclusion, screwdriver handles designed with combinations of circular and hexagonal lateral cross-sectional shapes with double frustum and cone longitudinal cross-sectional shapes appear to be optimal in this study.

Keywords: hand tools, hand ergonomics

1. Introduction

In many industrial work situations, such as the use of screwdrivers, torque exertion is required with the use of non-powered hand tools. Although powered hand tools are often available, common non-powered hand tools are still broadly used in industry [1]. BLS data (1995~2001) showed that injuries to the hand, finger, wrist, and shoulder are the most prevalent upper extremity injuries associated with non-powered hand tools. It is likely that these injuries could be reduced if the hand tools were ergonomically well-designed with emphasis on user comfort and safety [2].

The handle shape should be designed to optimize

subjective comfort, task performance, and the area of contact between the palm and the handle to provide better pressure distribution and reduce the unit pressure of the hand when working with hand tools. Mital and Channaveeraiah [3] reported that the triangular shape screwdriver handle exhibited maximum torque output followed by square and circular shape handles. There was no significant difference between square and circular shapes. Shih and Wang [4] also reported that triangular handles were associated with higher screwdriver torque output, followed by the square, hexagonal, and circular shape handle. Cochran and Riley [5] reported that rectangular and triangular handles were associated with the highest torque output

and circular and square handles were associated with the least.

Previous studies have investigated only the effects of longitudinal cross-sectional shape on screwdriver torque performance, rather than the effects of longitudinal and lateral cross-sectional shape combinations. Thus, the effects of handle shape including longitudinal cross-sectional shape (circular, hexagonal, triangular), lateral cross-sectional shape (cylindrical, double frustum, reversed double frustum, and cone), and surface material (rubber and plastic) in horizontal and vertical workpiece orientations on torque output, total finger force, and subjective discomfort were evaluated in this study.

2. Method

2.1. Subjects

Twelve males between the ages of 19 and 42 yrs (mean 24 yrs, $sd= 6.2$) were recruited from a university population. All participants were screened by questionnaire for any hand injuries or surgeries of the dominant hand.

2.2. Experimental design

Twenty-four screwdriver handles were constructed with combinations of longitudinal cross-sectional shape (circular, triangular, hexagonal) lateral cross-sectional shape (cylindrical, conical, double frustum, reverse double frustum), and surface material (plastic, rubber coated). All of the handles fit over the cylindrical shaft which accepted screwdriver bits (#2 Phillips). Table 1 shows detail dimensions of each screwdriver handle. Handle surface, lateral cross-sectional shape, and longitudinal cross-sectional shape were fixed, within-subjects variables. Work station orientation was a fixed, between-subjects variable. Subject was a random variable nested within work station orientation.

The dependent variables were maximum torque performance, total finger force and subjective discomfort. Total finger force was measured by Force Glove System [6, 7] and calculated by summing over all 16 individual force sensors.

2.3. Apparatus

All participants were asked to apply maximum

torque to the screw assembly on the torque sensor (*TQ202, 0-30Nm*) which was mounted in either the horizontal or vertical workpiece orientation. The heights of the “workpiece” were adjusted so that, while standing, the subject could maintain a straight elbow in the horizontal workpiece orientation, or, approximately 90° elbow flexion in the vertical workpiece orientation. All finger forces applied into handles were recorded by force glove system with 16 sensors.

2.4. Experimental procedure

Participants were asked to wait until they heard an audible “beep” signal, then increase the exertion of torque to their maximum level in a clockwise direction, and then hold their maximum torque output until the second beep sounded. At the end of each trial, participants reported their subjective discomfort ratings for the handle using a 7-point scale. The scale anchors were as follows: [most discomfort-7; somewhat discomfort-5; moderately discomfort-3; and no discomfort-1].

The maximum torque exertion was repeated two times for each handle, with two minutes of rest time between trials. Thus, a total of 48 torque outputs were recorded for each participant. Six of the twelve participants tested maximum torque exertion from the vertical workpiece orientation; the other six participants exerted their maximum torque from the horizontal workpiece orientation. The orientation was randomly assigned to each subject in this study.

3. Results

3.1. Subjective discomfort rating

Statistical analysis showed that handle surface, longitudinal cross-sectional shape, and lateral cross-sectional shape were significant factors on the subjective ratings of discomfort (all $p < .05$). The results of multiple comparisons indicated that participants rated Plastic surface handles with higher levels of discomfort than Rubber surface handles. In Figure 1.a, participants showed significant discomfort ratings for Triangular shape handles and Reversed Double Frustum handles. On average, Circular handles were rated with lower levels of discomfort than Hexagonal handles, although differences in the mean discomfort ratings were not evident. With respect to the lateral cross-sectional shape handles, on average,

Table 1
Dimensions of each screwdriver handle
(all handle length: 130mm)

	Lateral cross-sectional shape		Longitudinal cross-sectional shape		
			Circular	Hexagonal	Triangular
	Cylindrical	Diameter	45.0	44.5	42.0
	Reversed	Long-side	45.0	44.5	42.0
	Double Frustum	Short-side	36.0	35.5	33.5
		Long-side	45.0	44.5	42.0
	Double Frustum	Short-side	36.0	35.5	33.5
		Long-side	45.0	44.5	42.0
	Cone	Long-side	45.0	44.5	42.0
		Short-side	36.0	35.5	33.5

Double Frustum handles were rated the least comfortable followed by Cone, Cylindrical, and Reversed Double Frustum handles. The interaction effect between longitudinal and lateral cross-sectional shapes also indicated that circular and hexagonal shape combined with double frustum and cone shape handles were associated with less discomfort than other handles. Participants rated the vertical orientation with lower levels of discomfort than the horizontal orientation, although it was not statistically significant.

3.2. Torque output

The effects of handle surface, longitude-shape, and lateral cross-sectional shape on the maximum voluntary torque output were statistically significant. Rubber surface material handles were associated with higher torque output than Plastic handles. On average torque output with Plastic handles (4.86Nm) was approximately 84.8% of Rubber handles (5.73Nm). In Figure 1.b, Hexagonal (5.57Nm) and Circular (5.49Nm) handles were associated with statistically larger torque than Triangular (4.88Nm) handles. Double Frustum (5.44Nm) and Cone handles (5.37Nm) exhibited statistically greater torque output than Reversed Double Frustum (5.23Nm) and Cylindrical handles (5.14Nm). A multiple comparison test showed that Triangular handles and Cylindrical handles had the least torque output of the longitudinal and lateral cross-sectional shapes, respectively. With respect to the interaction between long-shape and lateral cross-sectional shape, Hexagonal and Circular handles, when combined with Double Frustum and Cone handles, exhibited higher torque output than any others. In general, participants could produce greater screwdriver torque output in the vertical (5.9Nm) than in the horizontal (4.69Nm) orientation.

3.3. Total finger force

The total finger force was defined as the sum of all 16 phalangeal segment forces. A significant longitudinal cross-sectional shape effect and interaction effects of orientation* longitudinal cross-sectional shape, surface*longitudinal cross-sectional shape, and longitudinal cross-sectional shape*lateral cross-sectional shape were found with respect to the total finger force (all $p < .05$, longitudinal cross-sectional*lateral cross-sectional shape, $p = .064$).

In Figure 1.c, total finger force was greatest when participants used the Triangular handles followed by the Hexagonal and Circular handles, and there was also a significant difference between Hexagonal and Circular handles ($p < .001$) in the horizontal orientation. There were no significant differences between the longitudinal cross-sectional shaped handles in the vertical orientation. In general, however, Triangular and Hexagonal handles in both orientations were associated with greater total finger force than Circular handles when exerting maximum torque. Total finger forces were similar in both horizontal (68.7N) and vertical (67.3N) orientation.

3.4. Individual finger/phalange force

In the analyses of individual finger force, the middle finger had the highest finger force and contribution to total finger force (40.9N, 39.3%), followed by the index finger (29.2N, 28.1%) and ring finger (27.7N, 26.5%). There were no significant differences between index and ring fingers. The little finger showed the least finger force and percentage contribution (6.5N, 6.2%). In terms of individual phalangeal force, the forces exerted by the distal phalanges was significantly higher than those by the

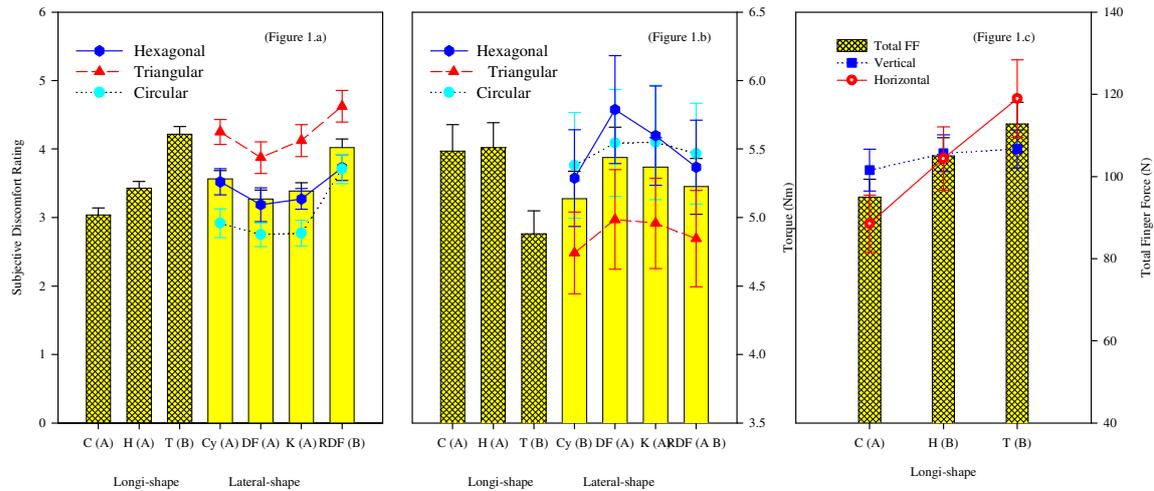


Fig. 1: Subjective discomfort ratings, torque, and total finger force for longitudinal and lateral cross-sectional-shape [alphabetic letters represent groupings by statistical significance; C-Circular; T-Triangular; H-Hexagonal; Cy-Cylindrical; DF-Double Frustum; RDF-Reversed Double Frustum; K-Cone handles]

other phalanges [distal phalange was the largest (49.2N, 47.3%), followed by the proximal (21.4N, 20.5%), metacarpal (18.9N, 18.1%), and middle phalanges (14.7N, 14.0%)].

In the analysis of individual segment force distributions, the distal phalanges of the middle, ring, and index fingers and the proximal and metacarpal phalanges of the index and middle fingers were the major contact areas in the maximum screwdriving task..

4. Discussion

In the analysis of handle surface material, rubber surface handles had better subjective ratings of discomfort and were associated with greater torque output than plastic surface handles. In a previous study Magill and Konz [8] reported a similar finding which was rubber handles had similar or better preferences and torque outputs than plastic or wood surface handles in an evaluation of seven industrial screwdrivers. Based on these findings, rubber coated handle surface may provide more comfort as well as friction to exert maximum torque performance.

With respect to longitudinal cross-sectional shape, participants rated circular and hexagonal handles as associated with less discomfort than triangular handles. In addition, hexagonal and circular handles were associated with higher torque outputs than triangular handles, while the measured total finger force was the largest when triangular handles were used. This

indicates that the designing screwdrivers with circular or hexagonal longitudinal cross-sectional shaped handles will reduce discomfort and improve torque output capability with less finger force. The relationships between handle longitudinal cross-sectional shape and torque output observed in the present study differ somewhat from those of previous studies. Cochran and Riley [5] indicated that the rectangular and triangular handles produced more torque than square and circular handles while Shih and Wang [4] reported that screwdrivers with triangular handles produced more torque than those with square, hexagonal or circular handles.

Most of these differences can be attributed to differences in the moment arms among the handle shapes tested in these studies. In Cochran and Riley [5] the ratios among the moment arms of the handles were 1.18:1.15:1.08:1.0 for rectangular, triangular, square, and circular, respectively. Shih and Wang [4] tested handles with moment arm ratios of 1.16:1.41:1.0:1.0 (triangular: rectangular: hexagonal: circular, respectively). The results of the present study indicated that circular and hexagonal handles, which had only slightly larger moment arms, were associated with higher torque capability than triangular handles (1.075:1.05:1.0 for circular: hexagonal: triangular). Thus, there is a positive relationship between the effective moment arm afforded by the shape and torque output [4, 6, 7, 9]. However, in Shih and Wang [4] and the present study hexagonal handles were associated with higher torque output than circular handles in spite of their same or slightly smaller moment arms.

Differences in handle orientation between the present study and the previous studies [3, 4, 5] might also have resulted in different relationship between torque output and moment arm ratios in the evaluation of handle shapes. In previous studies, the maximum screwdriver torques were measured at standing elbow height [5], at eye level with a straight elbow in the sitting posture [3], and at shoulder height with a straight elbow in a standing posture [4]. In the present study, an interaction was observed between longitudinal cross-sectional handle shape and workpiece orientation in which the torque capability in the horizontally and vertically oriented workpieces was affected differently by handle shape. Thus, the very different screwdriver orientations among the previous studies compared to the present might result in different handle shape/torque output relationships.

The analysis of lateral cross-sectional shape suggested a relationship between torque output and subjective preference similar to that reported by Magil and Konz [8]. Double frustum handles were associated with the least discomfort followed by cone, cylindrical, and reversed double frustum handles. The ordering of these handle shapes in terms of torque output followed a similar pattern.

The force glove system was used to investigate individual finger force distributions in the maximum screwdriver torque task and to identify the finger segments that were most involved in creating the grip force on the screwdriver. The average contributions of each segment showed similar trends with those reported in a previous investigation [6, 7].

Circular and hexagonal with double frustum and cone shape handles showed better subjective ratings and higher torque exertions than other handles, whereas overall triangular handles, especially with cone longi-shape, were associated with higher total finger forces than any other handle combinations in the maximum screwdriver torque task.

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Note: The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.