Screwdriver Bit Head Design – Effect of Phillips, Straight, and a Hybrid Design on Torque, Axial Force, and Effort Ratio

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Advancements in fastener technology have been complemented by the development of new types of screwdriver bits. While designs may vary, so may the force application requirements placed on the tool user. The primary objective of this experiment was to analyze the relationship between user applied torque and screwdriver bit design. A further objective was to utilize the results to develop an effort metric by which bits of different designs can be compared. Three types of screwdriver bit designs (straight, Phillips, and combination of straight/Phillips (ECX™)) were tested to determine how the design affects the amount and type of force applied by the user when performing a fastening task. The designs were tested to simulate fastener tightening and loosening operations. Sixteen participants were tested in this study. The data suggest there is no difference in user torque exertion between the ECX™ bit, Phillips, and the straight bit designs in either direction, 2.61-2.97 Nm for pronation and 2.63 -2.85 for supination. Mean axial force was significantly less for the Phillips (67 N) than the other 2 bits (72 and 80N). Although there was no significant effect of bit head design on maximal torque and axial force, the data suggest that the Phillips bit design may allow subjects to exert less axial force, which would result in a higher biomechanical effort ratio. A greater effort ratio would produce greater torque for the same axial force or the same torque for a lower axial force. Mean effort ratio for the Phillips bit was 3.6 N/N (Sup) and 4 N/N (Pro) and approximately 3.0 for the other two combinations of bits and directions. Subjective assessment indicated that users overwhelmingly preferred the Phillips bit design.

INTRODUCTION

Many modern cruciform fastener designs, especially those encountered during electrical work, feature geometry combining the self-centering aspect of the Phillips design with the simplicity of the slotted design (refer to **Figure 1**). In response, a new screwdriver bit design known as the ECX™ bit was recently developed by the Milwaukee Electric Tool Corporation, which features elements of both the straight blade and Philips head. This paper presents results of a formal evaluation of the ECX™ bit as compared to the Phillips and straight head bits. The ECX™ design is intended to increase bit retention in these fasteners, particularly the electrical screw, and it may have the benefit of decreasing the axial force ("push" force) required for proper bit retention. When a driver bit does not stay in the fastener, the user must apply an axial force in an attempt to increase bit retention. Reducing push force will minimize user fatigue (if the magnitude of reduction is significant), and it may also reduce an operator's risk of being affected by a musculoskeletal disorder affecting the wrist, elbow and shoulder. The ECX™ may also increase productivity. Research is needed to determine the efficacy of bit design advancements to inform hand tool designers and users.

Figure 1. Screw heads that match the straight, Phillips, and ECX™ bits (left to right).

LITERATURE REVIEW

A comprehensive literature review was conducted prior to initiating the testing phase of this study. Results identified factors shown to affect a person's ability to apply torque, although there is no consensus as to the extent each factor affects the results. For example, studies conducted by Rohmert (1966), Chaffin (1999), and O'Sullivan and Gallway (2005) suggest direction of torque application has an effect. They each report more torque can be applied in supination than in pronation. The fact that a majority of the population is right handed, coupled with these findings may, in part, explain why the convention for tightening a screw is clockwise and not counterclockwise. However, studies conducted by Wang and Strasser (1993) and Woodson (1981) suggest the opposite to be true. When forearm angle is factored in, the ability to apply torque is further affected. The work of O'Sullivan and Gallway (2005) demonstrate that as wrist angle deviates from neutral position, torque ability decreases. Sanchez (2008) showed that a pistol grip tool increases the ability to apply torque over an in-line straight screwdriver in both supination and pronation directions.

Published research is limited regarding the effect of bit type on torque exertion. Preliminary testing of torque exerted with the Phillips and Allen (hexagonal) screwdriver heads in the Marquette University Ergonomics Laboratory revealed no difference in torque for a conventional screwdriver but a 40% increase in torque with the Allen head with a pistol grip screwdriver. These studies used the same fixture and load cells as those employed in the present study.

METHODS

Approach

The research goal was to measure the torque and axial force applied by the operator to the handle of a manual screwdriver using three commercially available screwdrivers commonly used by tradesman.

Two hypotheses were tested: the ECX^{TM} bit enables the user to apply a greater torque than the Phillips bit, and there is a difference in axial force application between the three bits.

Experimental Design

The independent variable was screwdriver head bit with three levels (Phillips, straight, and ECX^{TM}) and direction (supination and pronation). The dependent variables were maximal torque (Nm), axial force (N), and subjective ratings. In addition, a new dependent variable called the "effort ratio" was created from the data.

Tools and Equipment

The screwdrivers chosen for this experiment were all manufactured by the Milwaukee Electric Tool Corporation (Brookfield, WI), having part numbers of 48-22-2012 (Phillips), 48-22-2041 (ECX), and 48-22-2021 (Straight). Each screwdriver had a length of 210 mm, and circular handle having a diameter of 30 mm. The tool shaft for each was 102 mm long and the shaft diameter was 6.4 mm.

A custom-designed fixture shown in **Figure 2** was used to measure torque and axial force. The torque device has a metal plate with tapped holes to allow for many possible load application points. The plate is mounted on a set of vertical guides with locking mechanisms that allow the height of the device to be adjusted between 10 and 60 cm above the base to accommodate subjects of different statures. At the rear of the fixture two load cells (Biometrics Ltd., Newport, UK) measure the torque (500 N) (force x moment arm length) and axial force (1000 N) (**Figure 2**). The torque load cell was connected to the text fixture by an adjustable linkage provided with holes spaced 2 cm apart. The linkage holes allow the investigator to adjust the fixture based on the levels of torque being measured to the tool. For this experiment the linkage was set to provide a 10 cm moment arm.

The screw head test specimen was a custom-made metal part designed to replicate a screw head commonly used by tradesmen. In this case, the screw specimen modeled a commercial electrical outlet, which is equivalent to an ANSI/ASME #10 machine screw (**Figures 3** and **4**). This size was chosen based on its prevalence in both residential and industrial construction. A representative screw was removed from an electrical outlet and measured to determine the head diameter, head height, and the bit reception geometry. The dimensions were used to create a 3-D model of the screw head using Pro/-Engineer software (PTC, Needham, MA). The screw head model was added to a square base to form the test specimen's final design. The Pro/E model was sent to a Selective Laser Sintering (SLS) machine that created a nylon plastic prototype for model verification. Once the model was approved, 40 sintered screw specimens were made from 420 stainless steel allowing for a new specimen to be used by each participant.

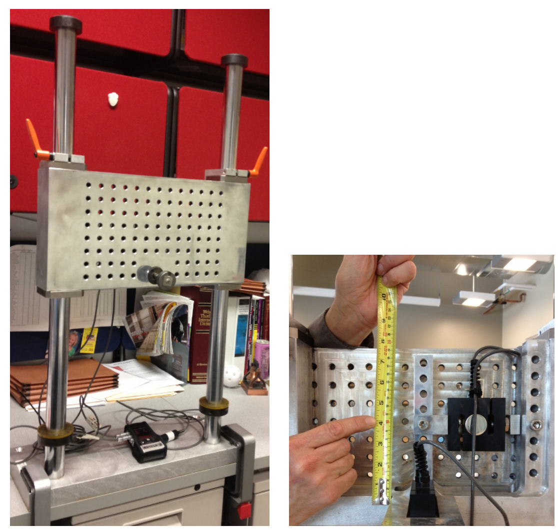

Figure 2. Height-adjustable fixture for measuring screwdriver torque and axial force (left). Load cells on rear of fixture (right).

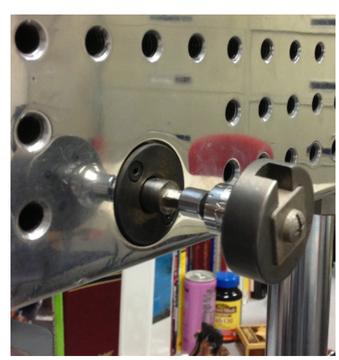

Figure 3. The screw head coupling on front of fixture.

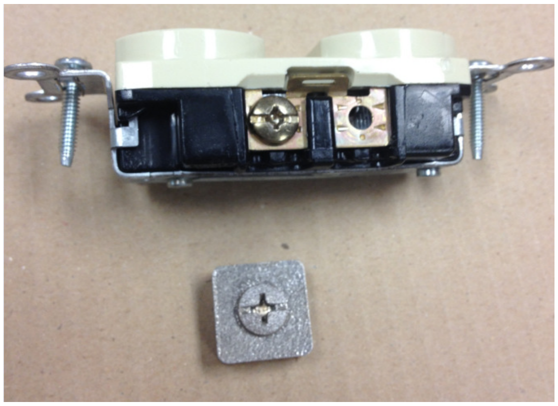

Figure 4. Comparison of electric screw and screw head test specimen made of stainless steel.

Each load cell was connected to a Biometrics Ltd. Datalog Wireless Bluetooth Data Unit (MWX8), which outputs raw data to a file. The sampling rate was set to 100Hz for both load cells. The data file was analyzed using the Biometrics software to determine the mean value of the central 2 seconds of the 5 second measurement. The raw data were post-processed using a calibration algorithm to determine the force (N) applied to each load cell. The calculated force applied to the torque load cell was multiplied by the moment arm (cm) to determine torque (Nm) applied by the subject.

Figure 5. Participant's upper extremity position when exerting maximum torque with a screwdriver.

Participants and Experimental Protocol

Sixteen participants (8 men and 8 women) from Milwaukee Electric Tool participated in the experiment. All participants were at least 21 years old and were familiar with tradesmen's use of screwdrivers and their applications. Their average height and weight were 167.6 cm (*SD* 11.3) and 65.7 kg (*SD* 20.4), respectively.

Participants read and signed an approved IRB form and then 10 anthropometric measurements were taken. The fixture was adjusted to the height of the participants elbow such that the forearm was horizontal with a 90° elbow angle (**Figure 5**). Maximal torque was exerted with the screwdriver in an in-line position in both supination and pronation (two trials in each direction) with each bit. Presentation order of the three bits, and torque application direction, were counterbalanced to control order and learning effects. Four participants were tested in a group, allowing at least two minutes of rest between consecutive exertions. A new test specimen of the screw head was used for each participant.

RESULTS

Maximum Torque

There was no significant difference in forearm torque among the three bits (p=0.93) and between pronation and supination (p=0.32) (**Figure 6** and **Table 1** and **Table 2**). The average torque ranged between 2.8 and 3.0 Nm for pronation and was approximately 2.65 Nm for supination.

Axial Force

The mean axial force was significantly less for the Phillips (67 N) than for the other 2 bits (72 to 80 N) (p<0.01). There was no difference in axial force between pronation and supination (p=0.82) (**Figure 7** and **Tables 3** and **4**).

Effort Ratio

To investigate the existence of a relationship between screwdriver head design and user effort, a new dependent variable - called the "effort ratio" - was calculated. The effort ratio is a dimensionless variable (N/N) calculated by dividing the tangential force causing the maximum applied torque and the axial force applied by the participant.

There was no significant difference in effort ratio among the 3 bits (p=0.169) although the data suggests the Phillips bit may have the potential for a significant effect if more participants were tested. The average effort ratio for the Phillips bit was 3.6 to 4 N/N and approximately 3.0 for the other two bits.

Subjective Assessment

The results of the subjective assessment were tabulated and the response percentages for each of the six test conditions levels were calculated. The Friedman's ANOVA Test was also applied. With rank ordering, the Phillips bit was rated the best by 56% of participants. There was no significant difference in ease of use between the bits.

DISCUSSION

This study analyzed whether a new bit created by Milwaukee Electric Tool was beneficial in terms of torque production and biomechanical effort compared to

Phillips and straight bits. The ECX bit was not found to enable participants to exert more torque (first hypothesis) or produce a higher (more beneficial) effort ratio. While there was no significant difference in average maximum torque among the three bits, the magnitudes of torque applied by test subjects were consistent with the literature, although on the lower end of the reported values from relevant studies. This may be, at least in part, due to the fact that in this study the subject was actually being tested more for physical ability to apply torque to a fastener and less on ability to apply torque in general, as was the case in many previous studies.

A new measure of biomechanical efficiency, called the "effort ratio," was proposed. The effort ratio is the ratio between the tangential force applied by the hands on the screwdriver handle divided by the axial force. A higher value of the ratio indicates more of the overall effort exerted by the participant goes into the application of torque and less into pushing the screwdriver bit into the fastener.

Despite the absence of a significant bit effect for effort ratio (p=0.169, **Table 5**), the data suggests that the Phillips bit may have the potential to have a greater effort ratio than the straight and ECX™ . With more statistical power (more participants), the Phillips may have a significantly greater effort ratio than the other two bits. The effort ratio of the Phillips bit appears to be influenced more by a reduced axial force than a greater torque. This finding is the opposite of conventional thought as the Phillips bit is assumed to be more susceptible to "camming out" of the fastener than the straight or the ECX™ and would require more axial force to keep the bit engaged in the screw head. The Phillips was hypothesized to require higher axial force to resist "camming out." The experimental results indicate the opposite (**Figure 7**).

There was no difference in average torque between pronation and supination. The literature has mixed findings regarding a direction effect.

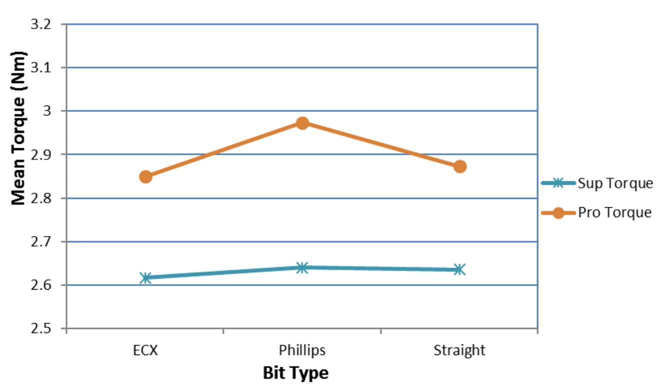

Figure 6. Average maximum forearm torque (Nm) as function of bit type and direction.

Table 1. Summary statistics for maximum forearm torque (Nm) (N=16)

Bit Type	ECX		Philips		Straight	
Direction	Sup	Pro	Sup	Pro	Sup	Pro
Mean	**2.62**	**2.85**	**2.64**	**2.97**	**2.63**	**2.83**
SD	1.13	1.17	1.17	1.32	1.10	1.13
Max	5.05	5.71	4.73	5.88	4.83	4.93
Min	0.94	1.25	1.16	1.15	1.10	0.89

Table 2. ANOVA results for average maximum forearm torque (Nm) (N=16)

		SS	d.f.	MS	F	P
Total SS		126.15	95			
Subjects		1.86	15	0.12	0.075	**1.00**
	Bit	0.09	2	0.04	0.028	**0.93**
	Dir.	1.71	1	1.71	1.037	**0.32**
	Bit x Dir.	0.05	2	0.02	0.015	**0.98**
Error		124.3	75	1.65		

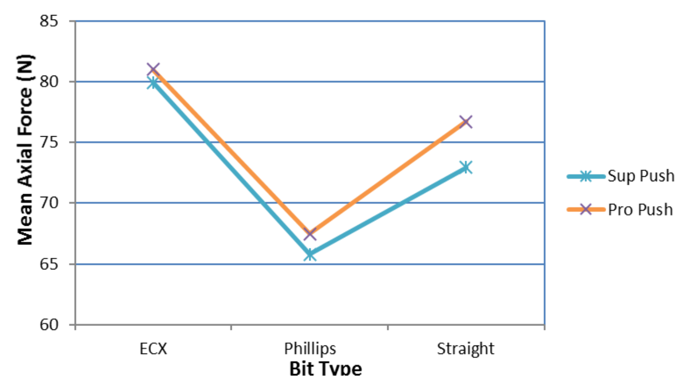

Figure 7. Average axial force (N) as function of bit type and direction

Table 3. Summary statistics for mean axial force (N) (*N*=16)

Bit Type	ECX		Philips		Straight	
Direction	Sup	Pro	Sup	Pro	Sup	Pro
Mean	**79.94**	**81.00**	**65.79**	**67.48**	**72.92**	**76.72**
SD	60.75	54.25	50.51	51.01	51.19	54.66
Max	224.5	196.3	181.99	191.2	187.4	204.8
Min	17.48	20.89	12.06	12.92	18.47	24.21

Table 4. ANOVA results for axial force (N) (*N*=16). Effects with *p*<0.05 highlighted in red.

		SS	d.f.	MS	F	P
Total SS		317131	95			
Subjects		151363	15	10090	4.56	**0.00**
	Bit	151248	2	75624	34.5	**0.00**
	Dir	49.1	1	49.1	0.02	**0.82**
	Bit x Dir	66.1	2	33.0	0.05	**0.96**
Error		165767	75	2210		

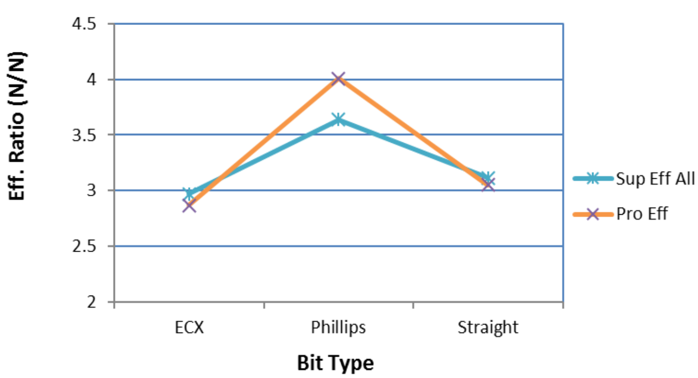

Figure 8. Average effort ratio (N/N) as function of bit type and direction

Table 5. ANOVA of Effort Ratio (N/N) (*N*=16)

		SS	d.f.	MS	F	P
Total SS		319.5	95			
Subjects		15.9	15	1.04	0.2	**0.997**
	Bit	14.76	2	7.30	1.823	**0.169**
	Dir.	0.11	1	0.15	0.08	**0.867**
	Bit x Dir	1.08	2	0.54	0.15	**0.874**

CONCLUSIONS

A new dependent variable of biomechanical effort was created from the torque and axial force data. The "effort ratio" is the ratio between the tangential force applied by the hands on the screwdriver handle divided by the push force. A higher value of the ratio indicates more of the overall effort exerted by the participant goes into the application of torque and less into pushing the screwdriver bit into the fastener. There was no significant difference in effort ratio between the three bit head designs, although the data suggests the Phillips head may have a higher effort ratio if more participants were tested.

Results did not show a difference in maximum torque, axial force, and effort ratio between maximal pronation and supination exertions.

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