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Pinch Effort Variations with Torque, Shape, Size, Sensation and Technique

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Abstract: While there have been some reviews on pinch force and pinch effort variations, it appears that few descriptive studies have been carried out on the variations of pinch efforts with different torque directions, shapes, sizes, tactile sensations and techniques. Hence, this study aims to explore the pinch effort variations with torque, shape, size, sensation and technique. Six screw knobs were developed and assessed with the participation of workers from a furniture manufacturing firm. The ratings on the efforts to pinch and turn the knobs were collected using surveys and analysed with reliability and descriptive analyses. From the results, the 5-lobes knob for both large and small sizes required the lowest pinch effort, while the spherical knob for both sizes required the highest pinch effort. The larger knobs required more turning effort than the smaller ones. The 3-jaw chuck turned out to be the most effortless pinch technique while the pulp-2 pinch required the most effort. Wearing nitrile gloves decreased pinch efforts, while wearing cotton gloves increased them. It also took lesser effort for the knobs to be turned in a clockwise torque direction compared to a counterclockwise direction. This study serves to improve the understanding on pinch force capacity with hope that workers can avoid overestimating or underestimating their efforts when pinching certain objects.

Key words: Torque direction, knob shape, knob size, tactile sensation, pinch technique

INTRODUCTION

Work-related hand injuries have been known to cause proliferated impacts on the health and productivity of industrial workers (McGorry, 2000; Ng *et al*., 2013e). Studies reveal that arm/hand injuries are considered as an important occupational safety and health concern in firms (Shock-Tek, 2013). In their quest to potentially discover a way to reduce these hand injuries, researchers have conducted numerous studies on different factors that influence grip strength to better understand the mechanisms behind various hand-related activities.

Researchers believe that factors such as different torque directions, object shapes, object sizes, tactile sensations and grip techniques are important to be considered in handgrip activities (Goldstein, 2010; Kumar, 2008; Seo and Armstrong, 2008; Seo *et al*., 2007, 2008a; Sesek *et al*., 2007). Their studies however have emphasized mostly on the exertion of effort from the palm of the hand and have yet to consider the effort exerted from the fingers (Amis, 1987; Gurram *et al*., 1995; Kong *et al*., 2004, 2007; Kong and Lowe, 2005a; Lee and Rim, 1991; Pylatiuk *et al*., 2006; Radhakrishnan and Nagaravindra, 1993). Although related reviews on this area have been done (Ng *et al*., 2012, 2013a, b; Ng and Saptari, 2012), there appears to be a lack of descriptive evidence on the variations of pinch efforts with different torque directions, shapes, sizes, tactile sensations and techniques.

Thus, this study aims to explore the pinch effort variations with torque, shape, size, sensation and technique. After a benchmarking activity was done on different types of knobs, 6 industrial screw knobs were designed, developed and tested via surveys in the aspects of shape, size, torque, sensation and technique. A total of 160 manual workers from a furniture manufacturing company in Penang participated in this survey study. Microsoft Excel 2010 was used to carry out the reliability and descriptive analyses of the data.

This study provides knowledge and explanations on the effects of different inducements of torque directions, shapes, sizes, tactile sensations and pinch techniques on pinch effort. It provides both the literature and quantitative evidence of the effects of these factors on pinch effort and can be used as guidelines to potentially reduce work-related hand injuries.

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PINCH EFFORT

Pinch effort is defined as the exertion from the compressing actions between the thumb and the index finger or both index and middle fingers and the thumb (Longii *et al.*, 1970). According to Kumar (2008), biomechanical factors such as pinch technique, pinch width, wrist angle, finger joint angle and finger-object contact area can affect pinch effort. Pinch effort can change when different subject samples, measurements and user categories are used (Imrhan and Rahman, 1995; Kumar, 2008).

TORQUE

According to Seo *et al.* (2008a), hand torque exertions are the basic requirements for many daily activities and are essential for better and more controlled manipulation. It is used to install or remove threaded and unthreaded parts, which involve the use of tools such as screwdrivers, spanners and screw knobs.

Slippages often slow down the completion of tasks and can lead to injuries. The torque generated by the hand while gripping prevents the gripped object from rotating along the fingers, producing thrust forces that prevent the object from sliding out from the fingers (Ng *et al.*, 2012, 2013d). Inward or clockwise torque refers to the hand's turning motion in the inner direction of the forearm, while outward or counterclockwise torque refers to the hand's turning motion in the outer direction of the forearm (Seo *et al.*, 2008a).

Torque is significantly affected by direction (Seo *et al.*, 2008a). Researchers found that the amount of axial torque increases with the inducement of grip force in a clockwise direction (Ng *et al.*, 2012; Seo *et al.*, 2011). Researchers were able to deduce that there is somehow an increase in force and torque generation when grip force is applied for instances such as twisting a door knob or a jar lid (Ng *et al.*, 2012, 2013d; Seo *et al.*, 2011).

SHAPE

According to Moes and Horvath (1999), the determination of the range of shapes and characteristics of a product comes first when designing a product. The shape of tools that require grip/pinch mechanisms plays an important role in ergonomics design considerations to ensure stress reduction on the hand muscles and finger tendons (Kong and Lowe, 2005b).

Yuan and Kuo (2006) mention that an object's handling properties can depend on its shape. For example, a ball shaped object has better handling properties compared to an oval shaped object and a cylindrical shaped object. Moes and Horvath (1999) point out that the shape of an object can affect the pressure distribution between the contact of the fingers and the object.

Shape characteristics are considered in designs to obtain a maximized contact area for better pressure distribution among fingers and reduced chances of pressure ridges and pressure concentration points while pinching (Karwowski and Salvendy, 1998). For example, a non-circular shaped object, such as a rectangular or triangular object, provides good pressure distribution and reduces the chances of hand slippages (Karwowski and Salvendy, 1998). This is because the edges of non-circular shaped objects help in resisting hand slippages when the object is gripped or turned (Karwowski and Salvendy, 1998). Pheasant and O'Neill (1975) also mention that non-circular shapes and knurled surfaces help torque exertion capabilities.

SIZE

The size of an object is a basic ergonomics criterion in design. Normally, the handling methods of an object, tool or device will be different due to its size (Kumar, 2008). Most studies show that the average adult male handgrip size is approximately 50 to 60 mm while the average adult female handgrip size is lesser than 5 mm (Bechtol, 1954; Cotten and Bonnell, 1969; Hertzberg, 1955; Montoye and Faulkner, 1964; Cotten and Johnson, 1970; Petrofsky *et al.*, 1980; Dvir, 1997).

Based on a person's hand size for example, the tool grip span of a design should be modified to a span where the grip position is comfortable enough for the user to apply a maximum handgrip force (Kumar, 2008). According to Kumar (2008), the hand torque increases as the diameter of the gripped object increases. Previous research suggests that it is difficult to turn an object with either a very small or very large diameter due to a loss in biomechanical leverage (Imrhan and Loo, 1989; Ng *et al.*, 2013c).

SENSATION

Sensation can be described as an occurrence when a stimulus that causes a physical or mental response, is received by one of the sensory organs of the body and fed into the brain (Tanaka and Numazawa, 2004). It affects the human physiologic systems like the respiratory, muscular, nervous, skeletal and circulatory systems (Ng *et al*., 2013f). The ability to grip and manipulate objects is affected by factors such as force, sensation impairment and friction (Engel *et al*., 2010b).

In pinching activities, the amount of generated pinch force may vary depending on the frictional condition of the pinched object's surface. According to Engel *et al.* (2010b), the increase of friction between the fingers and gripped object can reduce the minimum grip force required. Also, slippages can occur when this friction is lower than the ratio of shear forces to normal forces (Engel *et al*., 2010a). To prevent slippages, the force exerted must be within a range determined by the friction coefficient (Engel *et al*., 2010a).

Rock *et al.* (2001) carried out an experiment to evaluate the differences in an individual's grip strength with 3 different types of gloves. They found that it is important to consider the type of grip sensation when measuring the amount of optimum grip force that a worker requires to exert under various conditions.

TECHNIQUE

There are several types of known techniques in pinch grips. The 3 most commonly used pinch techniques are the pulp-2 pinch, 3-jaw chuck pinch and lateral pinch (Smith and Benge, 1985). In regards to pinch strength, the pulp-3 pinch is the strongest among other pulp pinches for both males and females (Swanson *et al*., 1974). Nevertheless, researchers discovered that manual labourers exert stronger lateral and 3-jaw chuck pinches with their major hand compared to sedentary and skilled labourers (Swanson *et al*., 1974). Studies also reveal that factors such as the occupation, grip span, position of the interphalangeal joint of the thumb and position of the elbow also affect the outcome of pinch strength (Apfel, 1986; Magee, 2008; Mathiowetz *et al*., 1985; Shivers *et al*., 2002; Swanson *et al*., 1974).

MATERIALS AND METHODS

In order to facilitate this study, six industrial aluminium screw knobs were designed and developed. Screw knobs are the most commonly used knobs in all kinds of manufacturing industries. A screw knob can be used in almost any industrial machine or hand tool and are often manufactured based on a strict standard (Monroe, 2013).

Benchmarking: A benchmarking activity was carried out on seven manufacturing companies on the classifications of knob shapes available in the market (Bonsheng, 2012; Chestten, 2012; Loi, 2012; RSC, 2012; WDS Component Parts, 2012; Winco, 2011, 2012a, b, c, d). About 184 industrial screw knobs were benchmarked.

Fig. 1: Six screw knobs developed based on benchmarked shapes and sizes

From the benchmarking activity, it was found that the spherical, cylindrical and 5-lobes knobs are among the most common shapes manufactured in the market. According to researchers, spherical objects tend to have better handling properties compared to objects of other shapes (Yuan and Kuo, 2006). Also, Karwowski and Salvendy (1998) suggest that non-circular objects, which normally have edges, can reduce the chances of hand slippages while the object is gripped or turned. A slight and uniform surface indentation also allows the torque exertion capability to increase (Karwowski and Salvendy, 1998). The aforementioned evidence from the data and literature justify the emphasis of this research on spherical, cylindrical and 5-lobes knobs.

A second benchmarking activity was then carried out on the classification of knob sizes according to the type of common knob shapes identified in the first benchmarking activity (Bonsheng, 2012; Chestten, 2012; Loi, 2012; RSC, 2012; WDS Component Parts, 2012; Winco, 2011, 2012a, b, c, d).

Based on the benchmarking data, the cylindrical, spherical and 5-lobes knobs are often manufactured in the ranges of 12-63, 12-60 and 32-63 mm, respectively. The upper and lower limits of these ranges are thus used to create the large and small knobs of these identified shapes. Figure 1 shows the six screw knobs developed for this study based on the benchmarked shapes and sizes.

Participants: This study also involved the participation of 160 manual workers from a furniture manufacturing company in Penang, Malaysia. The workers were first given a short briefing before the test to ensure that they understood the procedures involved. They were also required to sign a consent form prior to the study. Subjects were requested to comply with the following guidelines:

- Assume a standing posture
- Ensure that the elbow is flexed at a 90° angle
- Ensure that the forearm is in a neutral position
- Use the preferred hand to pinch the knob

Every subject was presented with the test model (Fig. 1) and asked to pinch the screw knobs. The subjects were then requested to turn each of the screw knobs in a clockwise and counterclockwise direction (Seo *et al.*, 2008a). As suggested by Rock *et al.* (2001), three types of sensation conditions were used. These conditions include:

- Wearing cotton gloves to simulate reduced sensation
- Wearing nitrile gloves to simulate increased sensation
- Not wearing any gloves to simulate normal sensation

Also, three commonly used pinch techniques (pulp-2 pinch, lateral pinch, 3-jaw chuck pinch) were used during the pinching experiment (Smith and Benge, 1985).

For every turn made by the subject with the combination of the abovementioned conditions, a question was asked from a survey developed for this study. This survey utilised a modified version of the Borg CR10 scale (Borg, 1982), where a scale ranging from 0 to 10 was used to indicate the load of physical work perceived. The rating "0" indicated no effort at all whereas the rating "10" indicated tremendous effort. The responses were recorded and analysed descriptively using Microsoft Excel 2010. The following procedures were used for this study:

- The subject is required to turn the sample knobs using his/her bare hands
- All of the knobs are pinched in clockwise and counterclockwise torque directions using the 3-jaw chuck pinch technique
- After pinching the knobs, the subjects are required to provide his/her rating on the level of effort used for the pinch
- Steps 1 to 3 are repeated using the pulp-2 pinch and lateral pinch techniques
- Steps 1 to 4 are also repeated using cotton gloves (for reduced sensation) and nitrile gloves (for increased sensation)

Figure 2 presents an example of the different pinch techniques employed on a cylindrical knob. Figure 2a shows how a three jaw chuck pinch technique can be applied on a knob. Figure 2b shows how a pulp-2 pinch technique can be applied, while Fig. 2c presents how a lateral pinch technique can be applied.

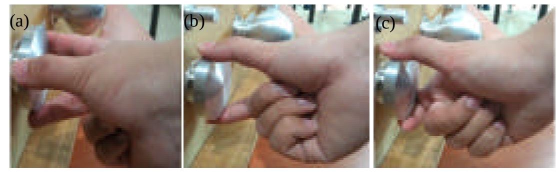


Fig. 2(a-c): Examples of different pinch techniques applied on a cylindrical knob (a) Three jaw chuck pinch technique, (b) A pulp-2 pinch technique and (c) Lateral pinch technique

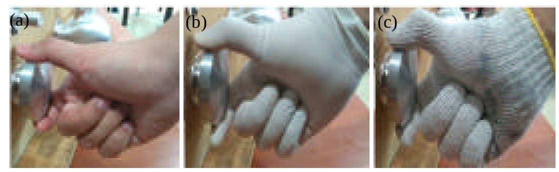


Fig. 3(a-c): Examples of different tactile sensations used when pinching a cylindrical knob (a) Cylindrical knob pinched with bare hands, (b) Cylindrical knob pinched with increased sensation and (c) Cyilndrical knob pinched with reduced sensation

Table 1: Cronbach's alpha reliability test results for the pinch effort data

Test results	Values
Standard deviation	48.137
Alpha	0.954
Standard error of mean, SEM	10.330

Figure 3 shows an example of the different tactile sensations used when pinching a cylindrical knob. Figure 3a demonstrates how a cylindrical knob can be pinched with the participant's bare hands (without gloves). Figure 3 (b) shows how a participant can pinch a cylindrical knob with increased sensation (wearing nitrile gloves). Figure 3 (c) presents how a participant can pinch a cylindrical knob with reduced sensation (wearing cotton gloves).

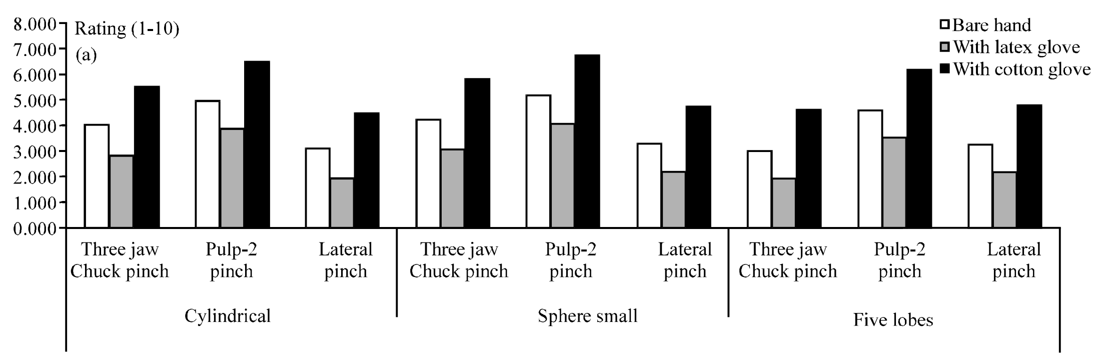
RESULTS AND DISCUSSION

The Cronbach's alpha reliability analysis was used to test the reliability of the data collected. Table 1 shows the Cronbach's alpha reliability test results for the pinch effort data.

The alpha value obtained is 0.954, which is more than the minimum acceptable alpha value of 0.7. An alpha value more than 0.7 signifies that the data obtained for this study has good internal consistency and high reliability (Cronbach and Shavelson, 2004;

Table 2: Mean pinch effort ratings for combinations of different torque directions, shapes, sizes, sensations and techniques

		Clockwise torque			Counterclockwise torque		
Variables/ratings		Bare hand	With nitrile glove	With cotton glove	Bare Hand	With nitrile glove	With cotton glove
Small size							
Cylindrical	3-Jaw chuck	4.036	2.827	5.564	5.636	4.191	6.991
	Pulp-2	4.982	3.855	6.500	6.527	5.164	7.864
	Lateral	3.073	1.936	4.445	4.645	3.309	5.836
Spherical	3-Jaw chuck	4.218	3.073	5.818	5.918	4.455	7.164
	Pulp-2	5.164	4.055	6.764	6.855	5.491	8.045
	Lateral	3.282	2.209	4.745	4.955	3.527	6.127
5-Lobes	3-Jaw chuck	3.027	1.964	4.600	4.536	3.100	5.882
	Pulp-2	4.600	3.509	6.209	6.091	4.764	7.391
	Lateral	3.227	2.209	4.755	4.755	3.364	6.036
Large size							
Cylindrical	3-Jaw chuck	3.264	2.164	4.873	4.982	3.582	6.373
	Pulp-2	5.136	4.018	6.682	6.855	5.491	8.155
	Lateral	3.845	2.764	5.364	5.536	4.164	6.773
Spherical	3-Jaw chuck	3.527	2.427	5.045	5.118	3.645	6.455
	Pulp-2	5.327	4.182	6.836	6.900	5.618	8.127
	Lateral	3.991	2.945	5.464	5.545	4.173	6.773
5-Lobes	3-Jaw chuck	2.845	1.782	4.400	4.527	3.100	5.918
	Pulp-2	4.891	3.791	6.373	6.545	5.173	7.818
	Lateral	3.700	2.591	5.200	5.336	3.936	6.600



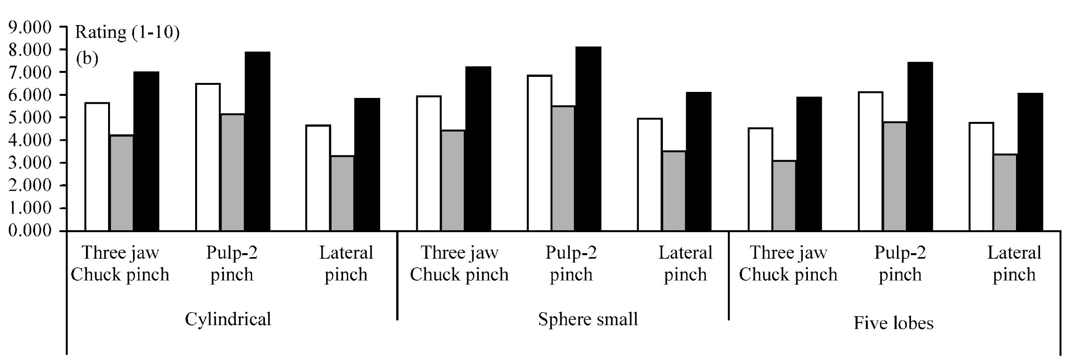


Fig. 4(a-b): Mean effort ratings of shape for small knobs in, (a) Clockwise and (b) Counterclockwise directions

Nunnally and Bernstein, 1994). Thus, the data are reliable enough for further analyses. A descriptive analysis was carried out using Microsoft Excel 2010. The results obtained on the mean pinch effort ratings are tabulated in Table 2.

Figure 4a and b summarise the mean effort ratings of different small knobs using the different pinch techniques in both clockwise and counterclockwise directions. Each colour bar indicates the different tactile sensations used. Blue represents the sensation with bare hands, while red and green represent the sensation with nitrile and with cotton gloves.

The results show that the 5-lobes knob has the lowest mean effort rating among the industrial screw

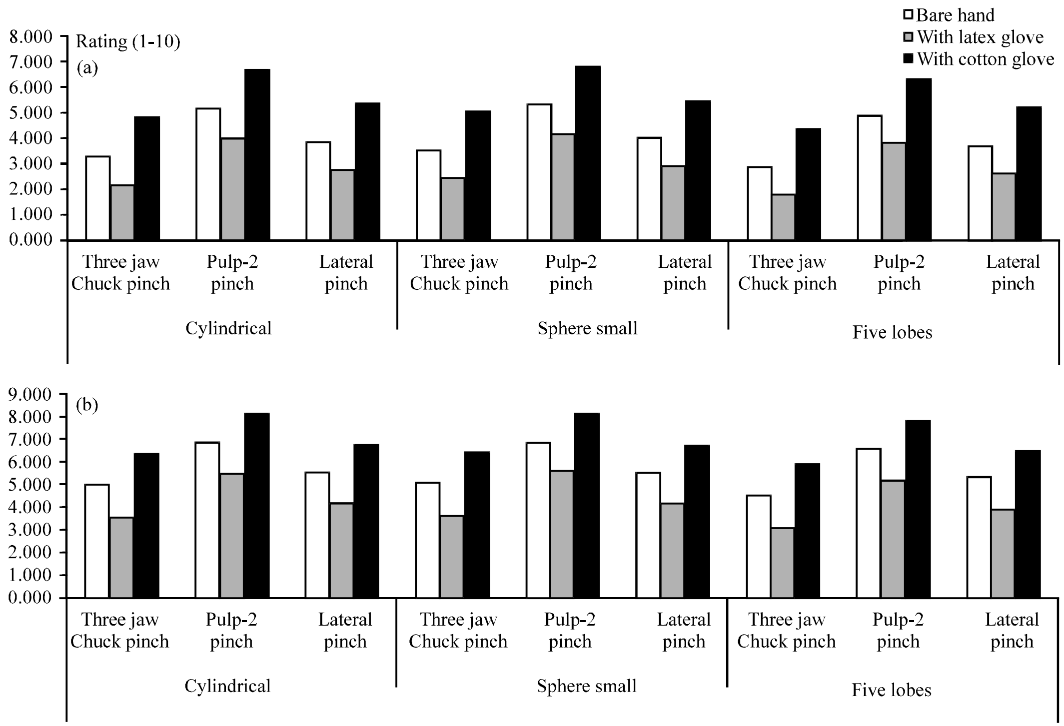


Fig. 5(a-b): Mean effort ratings of shape for large knobs in, (a) Clockwise and (b) Counterclockwise directions

knobs, while the spherical knob has the highest mean effort rating for all pinch techniques and tactile sensations. The effort for the cylindrical knob however is rated moderately between the 5-lobes knob and spherical knob.

The mean effort ratings of shape for large knobs are shown in Fig. 5a and b. According to these figures, the spherical knob has the highest mean effort rating compared to the cylindrical knob and the 5-lobes knob while the 5-lobes knob has the lowest mean effort rating with the use of every pinch technique and tactile sensation.

From the results, the 5-lobes knob for both large and small sizes appear to be the most preferred shape in terms of effort among the other shapes tested in the survey, while the spherical knob for both sizes is the most undesired shape. This is because the 5-lobes knob has edges that help resist hand slippages when turning the object as mentioned by Karwowski and Salvendy (1998). This helps in increasing the capability of torque exertion (Mital and Channaveeraiah, 1988).

The cylindrical and spherical knobs however do not have edges, thus causing potential hand slippages to occur when turning the objects. The edges of the 5-lobes knobs act as aids for the fingers when turning the knob.

The mean effort ratings of size for the cylindrical knob using different pinch techniques in both clockwise and counterclockwise directions are shown in Fig. 6a and b. From the results, it seems that the large cylindrical knob requires more turning effort compared to the small cylindrical knob.

The mean effort ratings of size for the spherical knob using different pinch techniques in both clockwise and counterclockwise directions are shown in Fig. 7a and b. From the results, it appears that the large spherical knob needs more turning effort compared to the small spherical knob.

The mean effort ratings of size for the 5-lobes knob using different pinch techniques in both clockwise and counterclockwise torque directions are summarised in Fig. 8a and b. From the results, the large 5-lobes knob needs more turning effort compared to the small 5-lobes knob.

Based on the results, approximately all the large knobs require more turning effort than the small knobs. According to Kumar (2008), certain biomechanical factors will affect the strength of pinching. These factors may include pinch techniques, pinch width, wrist angles, finger joint angles and contact area between the finger and object.

The results in Fig. 9a, b and c show that the lateral pinch is the most effortless pinch technique for the knobs because less effort was exerted by most of the users with

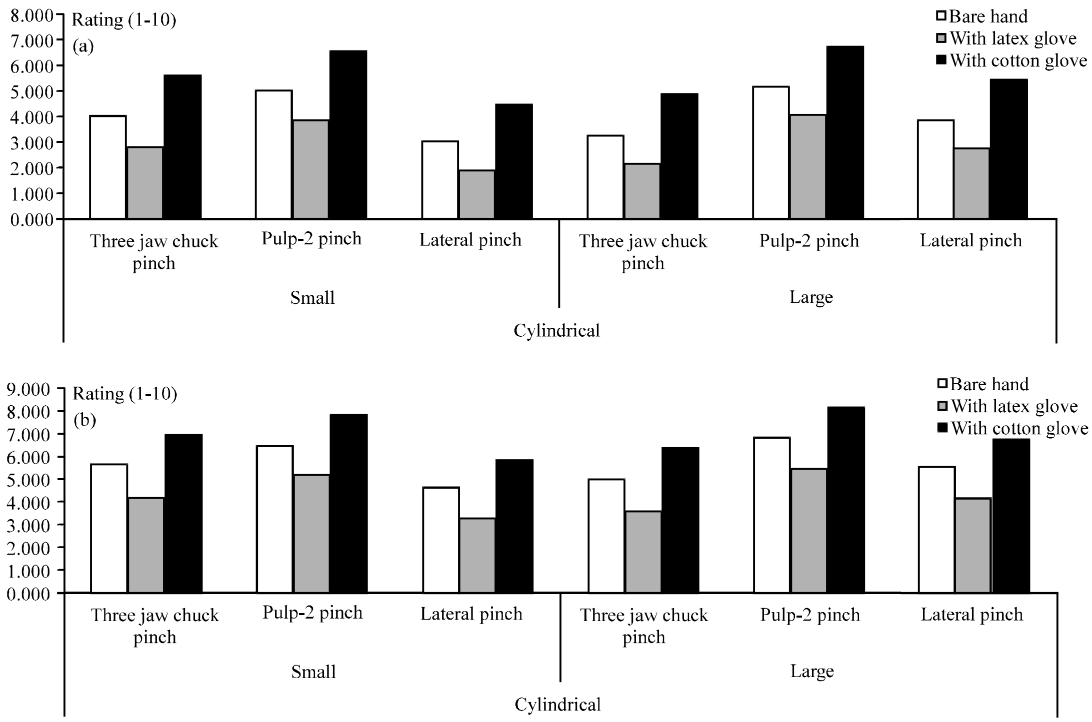


Fig. 6(a-b): Mean effort ratings of size for cylindrical knobs in (a) Clockwise and (b) Counterclockwise directions

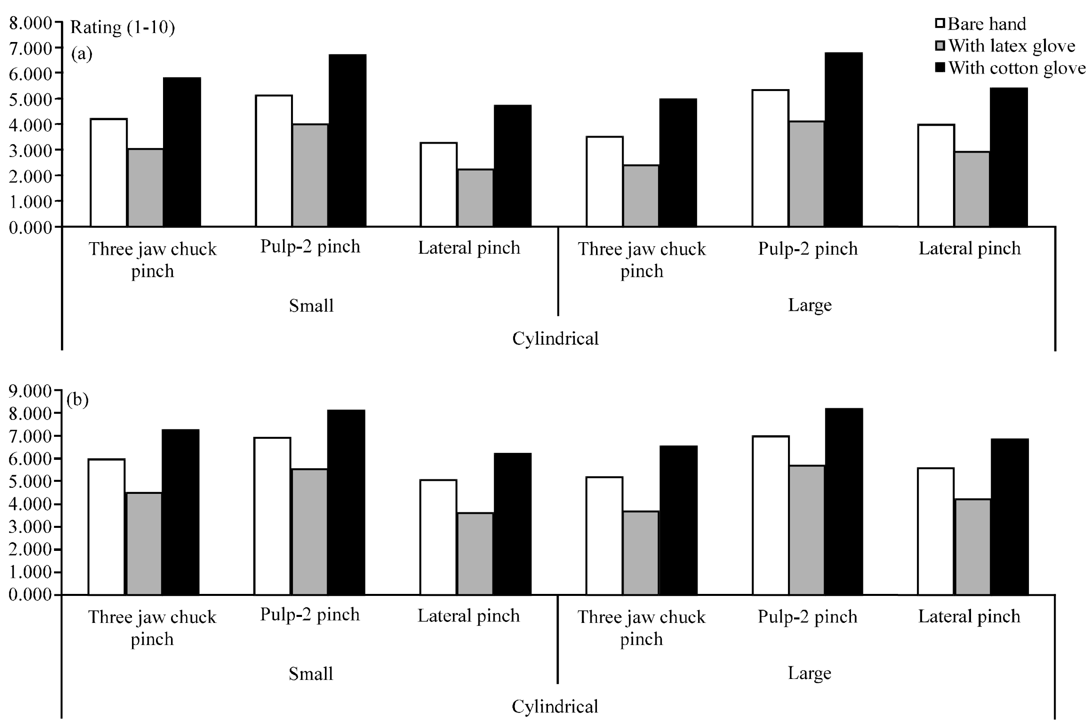


Fig. 7(a-b): Mean effort ratings of size for spherical knobs in, (a) Clockwise and (b) Counterclockwise directions

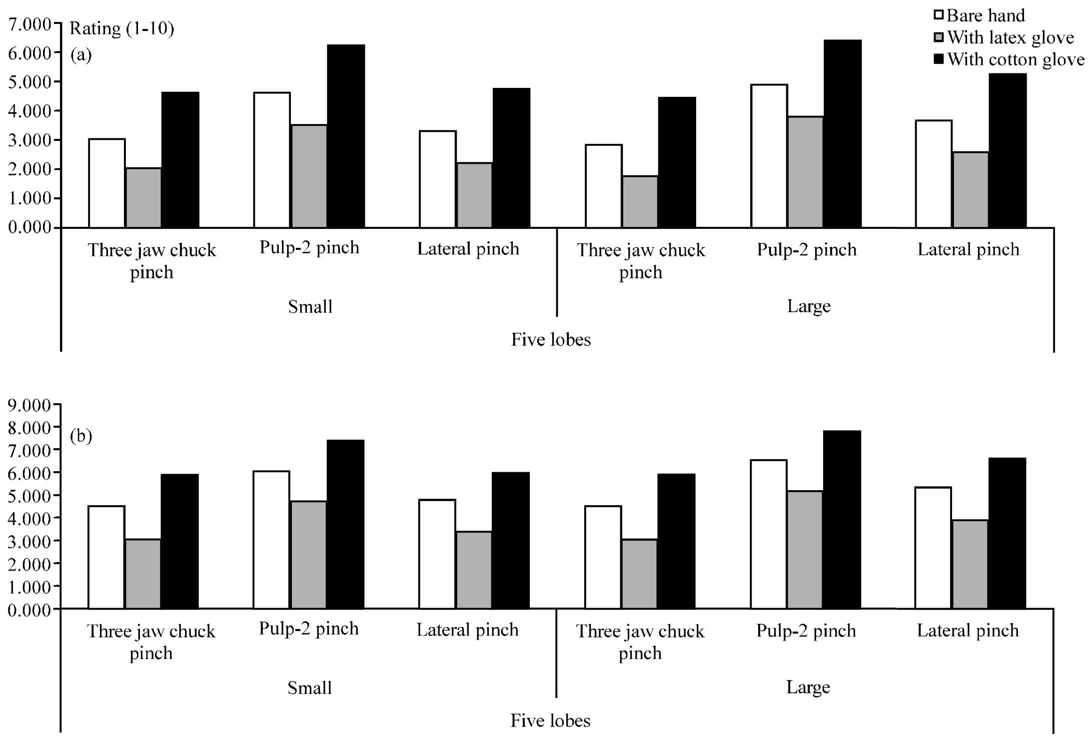


Fig. 8(a-b): Mean effort rating of size for 5-lobes knob in, (a) Clockwise and (b) Counterclockwise direction

this technique compared to the other 2 techniques. This is due to the fact that a more secure grip can applied when using a lateral pinch, since the thumb is proficient in abduction and adduction (Clarkson, 1999).

On the other hand, it is reasonable to conclude that the pulp-2 pinch is the most non-preferred technique to be applied on the knobs as the results show that it requires the highest mean effort. According to Swanson *et al.* (1974), only 25% of individuals prefer to use the pulp-2 pinch technique when pinching small objects with the major hand. This finding suggests that the pulp-2 pinch is less preferred in this study.

The results in Fig. 10a, b and c support that the 3-jaw chuck pinch is the most effortless pinch technique for the knobs compared to the other 2 pinch techniques due to the fact that less mean effort was exerted by the users with this technique compared to the other 2 techniques. According to Imrhan and Rahman (1995), the 3-jaw chuck pinch is stronger than the lateral and pulp-2 pinch, while the lateral pinch is stronger than the pulp-2 pinch.

The 3-jaw chuck pinch also provides a higher average pinch strength compared to the lateral pinch (Swanson *et al.*, 1974). Nevertheless, it is also reasonable to conclude that the pulp-2 pinch is the most non-preferred technique to be applied on the knobs as the results show that it required the highest mean effort.

Table 3: The friction coefficient for different tactile sensations

Sensation	Thickness of the gloves (mm)	Friction coefficient (Grip and Aluminum's surface)
Bare hands	-	0.56 (Motawar *et al.*, 2011)
Nitrile gloves	0.5	1.1 (Motawar *et al.*, 2011)
Cotton gloves	1.8	0.373-0.453 (Lima *et al.*, 2005)

According to Imrhan and Rahman (1995), the pulp-2 pinch is weaker compared to the 3-jaw chuck pinch and lateral pinch.

Based on the results from Fig. 9 to 10, different characteristics can be observed in the mean pinch efforts according to different tactile sensations. It was found that wearing nitrile gloves appears to always help in decreasing the effort used to turn the knobs.

As observed from the analysis, the use of different tactile sensations can alter pinch effort. The friction coefficient for different tactile sensations can be summarized in Table 3. In this table, an aluminum surface was used as a reference since the screw knobs in this study were made from aluminum.

By relating the friction coefficient of the materials to the results analyzed, the pinch effort appears to be affected by the friction coefficient of the glove's contact with the surface of the knobs. By wearing nitrile gloves (highest friction coefficient), the pinch effort appears to decrease.

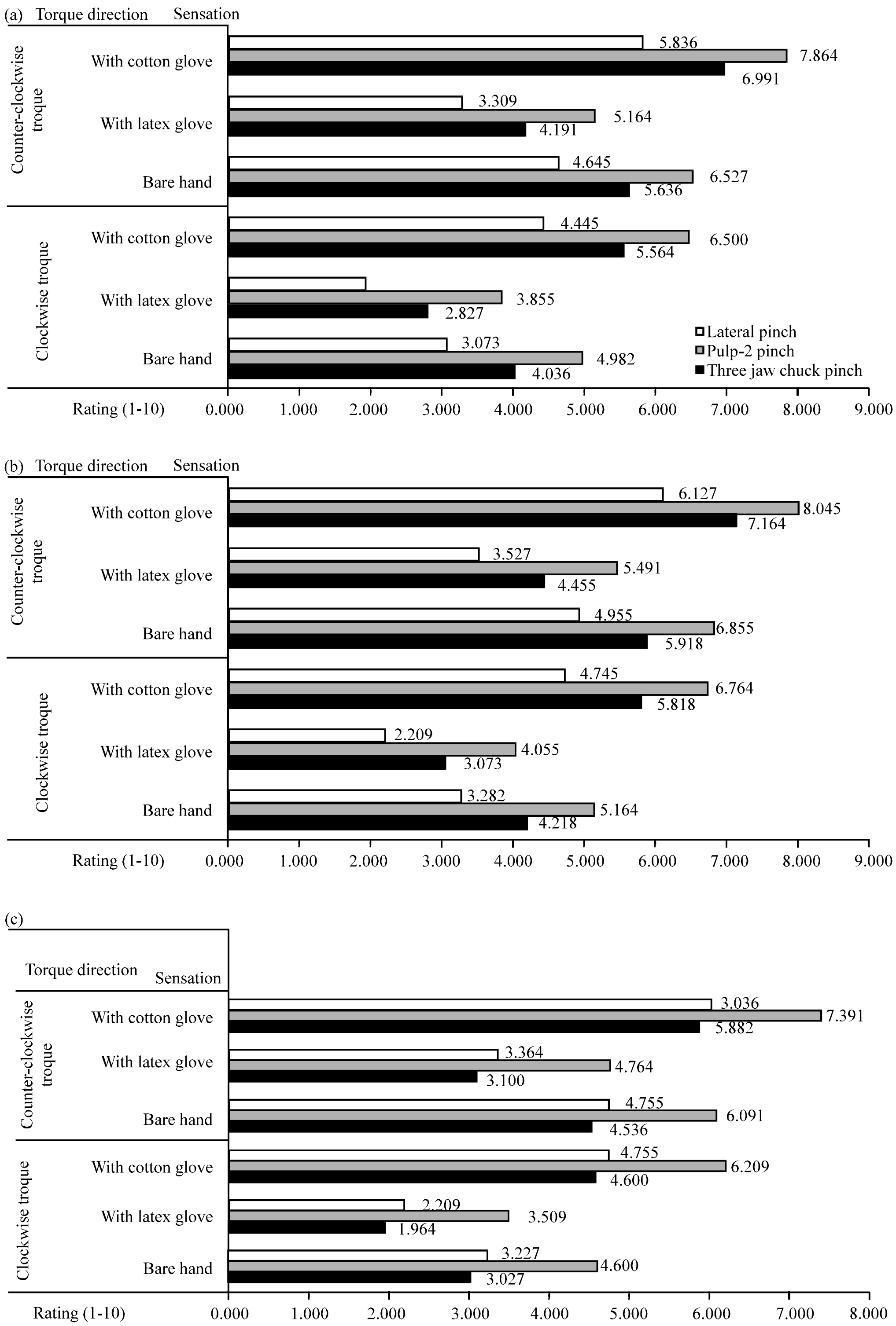


Fig. 9(a-c): Mean effort ratings for, (a) Small cylindrical, (b) Spherical and (c) 5-lobes knobs

Regardless of the pinch techniques used, the friction coefficient plays a very important role in providing a better grip on the knobs. From the data obtained, it is agreed that individuals can produce greater pinch forces

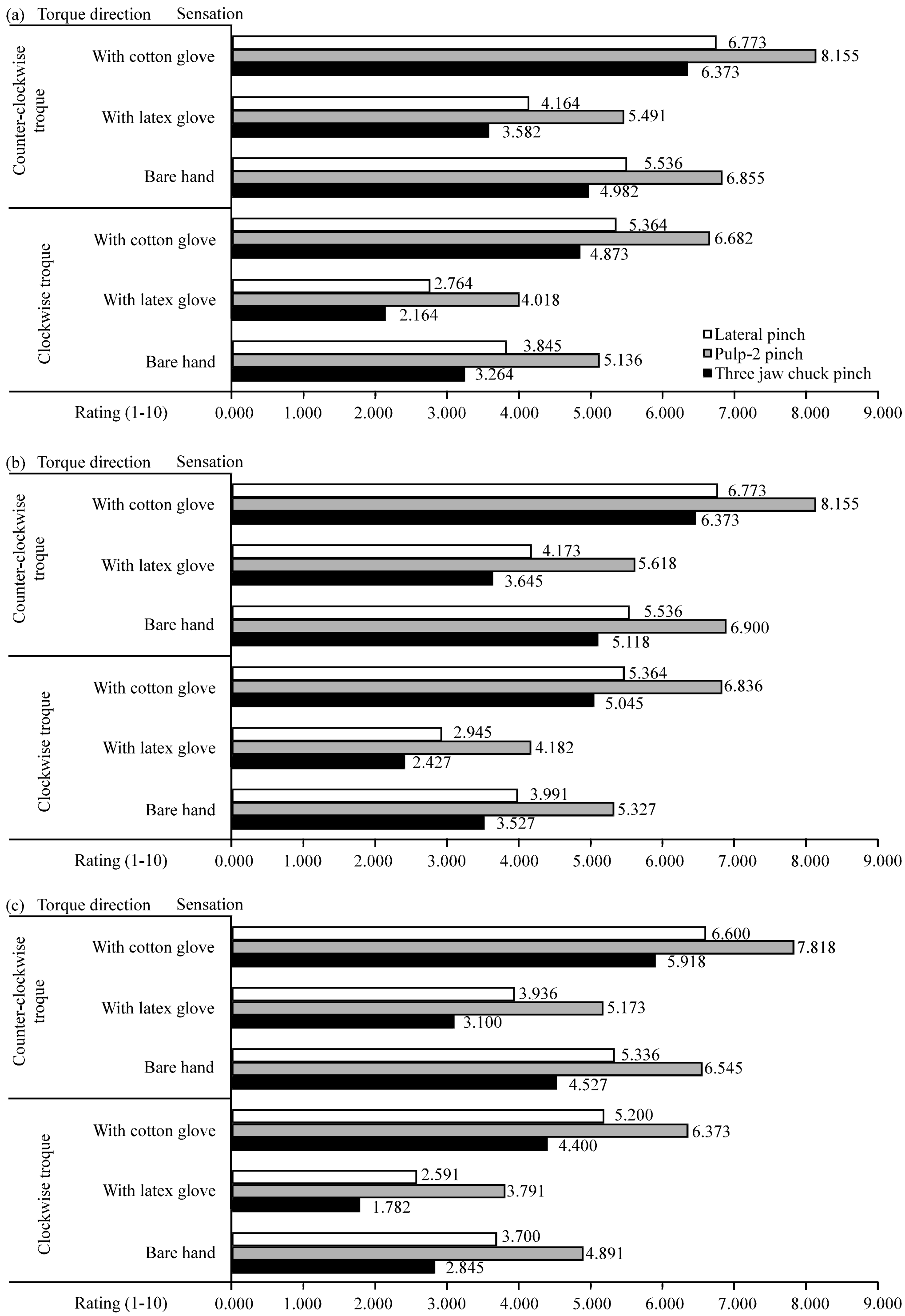


Fig. 10(a-c): Mean effort ratings for, (a) Large cylindrical, (b) Spherical and (c) 5-lobes knobs

when pinching objects with a high friction coefficient between the fingers and the pinched surface (Engel *et al.*, 2010a).

The effects of clockwise and counterclockwise torque directions on pinch efforts can also be observed in this study. It generally takes lesser effort for the knobs to be turned in the clockwise torque direction as compared to the counterclockwise direction, regardless of the shapes, sizes, techniques and tactile sensations used.

According to Seo *et al.* (2008b), larger grip forces can be generated with the application of inward (clockwise) torque. This is because the exerted torque is 22% stronger in this particular direction, which implies that the pinch-and-turn effort on an object can be reduced when employed in this particular direction (Seo *et al.*, 2008b; Ng *et al.*, 2012).

CONCLUSION

Ergonomics issues can cause occupational hand injuries and musculoskeletal disorders if not addressed quickly. Nonetheless, by looking into the previous and recent research, this study offered a review and simple analyses on how the considerations of shape, size, pinch technique, torque direction and tactile sensation can alter an individual's pinch effort.

Based on the results, the 5-lobes knob for both large and small sizes appear to be the most preferred shape among the other knob shapes tested, while the spherical knob for both sizes is the most non-preferred shape. Also, the larger knobs require more turning effort than the smaller knobs. The 3-jaw chuck pinch is the most effortless pinch technique for the 3 knobs in this study, whereas the pulp-2 pinch requires the most effort.

Wearing nitrile gloves appears to decrease the pinch efforts of the test subjects, while wearing cotton gloves increases them. It also takes lesser effort for the knobs to be turned in the clockwise torque direction as compared to the counterclockwise direction.

Theoretical implications: By understanding the considerations of shape and size in the design of knobs, this study offers an exploratory avenue for both designers and researchers. Through the findings in this study, the design of industrial screw knobs can be further improved to be more ergonomic and aesthetic.

The preliminary findings of the study allow the other researchers to potentially determine the relationships among shape, size, pinch techniques, tactile sensations, torque directions and pinch forces for future studies via statistical predictive modeling. Using the descriptive results from this study, researchers can enhance their future predictions on pinch forces and expand their results in the field of hand tool ergonomics. This study also creates a possibility of developing a framework that potentially enhances the safety margin of pinching activities in a more precise and realistic way.

This study also helps researchers in simulating the minimum effort required by the fingers to pinch certain knob designs. The prospective research outcome of this study can involve the enhancement of hand tool designs to be more accommodating to the users' fingers and less strenuous for manual work activities.

Practical implications: Using the results of this study as preliminary guidelines, an effective prevention strategy or solution can be created to address the problems related to manual activities with high pinch forces. For example, design guidelines can be developed for further improvements on the design of manual tools in order to reduce muscle strains or tendon injuries and hence improve quality of life.

This study may be beneficial to ergonomists, researchers, designers and engineers, who are involved in the general design of hand tools. The findings of the study can serve as a reference for designing activities that involve hand tools of irregular shapes and sizes. It helps to ensure that the design of hand tools is within the preferred range of shapes and sizes for pinching activities as determined by this study. It will guide the engineers and designers in the design and production of an ergonomic hand tool. The literature review of this study can also help these engineers and designers identify the factors that potentially affect a person's pinch grip strength.

Directions for future research: There are still some improvements that can be done in future for this study. For instance, an experimental design method can be used in lieu of the survey research method employed in this study. To facilitate this, pressure sensors, force measurement gloves and sensor arms can be used to accurately measure the actual effort needed to pinch the knobs under the varying conditions of shape, size, torque direction, pinch technique and tactile sensation. By directly measuring pinch force data through these sensors, more accurate analyses can be conducted to improve the findings of this study. The findings of the experimental research also eliminate the uncertainty in the data from the perception of the respondents in the survey research.

In order to improve these results for further establishments in ergonomic product design and research, further analyses and theoretical groundwork must be done, namely on measurement methods and designs that involve pinch grips. Keeping this into account, other factors that affect pinching activities should also be considered in the future so that a more accurate statistical predictive modeling can be done to potentially reduce the risks of sustaining hand-related injuries.

Relevance to ergonomics theory: This study serves as a preliminary guideline for safer and more ergonomic procedures involving pinch activities at the workplace. It also serves to potentially improve the understanding of pinch force capacity with the anticipation that manual workers can avoid overestimating or underestimating their pinch efforts when pinching certain objects.

REFERENCES

Amis, A.A., 1987. Variation of finger forces in maximal isometric grasp tests on a range of cylinder diameters. J. Biomed. Eng., 9: 313-320.

Apfel, E., 1986. The effect of thumb interphalangeal joint position on strength of key pinch. J. Hand Surg., 11: 47-51.

Bechtol, C.O., 1954. Grip test the use of a dynamometer with adjustable handle spacings. J. Bone Joint Surg., 36: 820-832.

Bonsheng, H., 2012. Hengshui bonsheng mechanical and electrical products Trade Co., Ltd. http://1088834.en.makepolo.com/.

Borg, G.A.V., 1982. Psychophysical bases of perceived exertion. Med. Sci. Sports Exercise, 14: 377-381.

Chestten, 2012. Chestten gripping and positioning. http://www.chestten.com/.

Clarkson, H.M., 1999. Musculoskeletal Assessment: Joint Range of Motion and Manual Muscle Strength. 2nd Edn., Lippincott Williams and Wilkins, Philadelphia, USA.

Cotten, D.J. and A. Johnson, 1970. Use of the T-5 cable tensiometer grip attachment for measuring strength of college men. Res. Q., 41: 454-456.

Cotten, D.J. and L. Bonnell, 1969. Investigation of the T-5 cable tensiometer grip attachment for measuring strength of college women. Res. Q., 40: 848-850.

Cronbach, L.J. and R.J. Shavelson, 2004. My current thoughts on coefficient á and successor procedures. J. Educ. Psychol. Measure., 64: 391-418.

Dvir, Z., 1997. The measurement of isokinetic fingers flexion strength. Clin. Biomechanics, 12: 473-481.

Engel, A.K.J., L.R. Enders and N.J. Seo, 2010a. High coefficient of friction at the hand-object interface contributes to increased maximum grip force by the phalanxes during power grip. Proceedings of the 34th Annual Meeting of the American Society of Biomechanics, August 18-21, 2010, Providence, RI., USA.

Engel, A.K.J., L.R. Enders, K.G. Keenan and N.J. Seo, 2010b. Grip surface friction affects maximum tip pinch force. Proceedings of the 34th Annual Meeting of the American Society of Biomechanics, August 18-21, 2010, Providence, RI., USA.

Goldstein, E.B., 2010. Sensation and Perception. 6th Edn., Wadsworth Group, USA .

Gurram, R., S. Rakheja and G.J. Gouw, 1995. A study of hand grip pressure distribution and EMG of finger flexor muscles under dynamic loads. Ergonomics, 38: 684-699.

Hertzberg, H.T.E., 1955. Some contributions of applied physical anthropology to human engineering. Ann. N. Y. Acad. Sci., 63: 616-629.

Imrhan, S.N. and C.H. Loo, 1989. Trends in finger pinch strength in children, adults and the elderly. Hum. Fact., 31: 689-701.

Imrhan, S.N. and R. Rahman, 1995. The effects of pinch width on pinch strengths of adult males using realistic pinch-handle coupling. Int. J. Ind. Ergon., 16: 123-134.

Karwowski, W. and G. Salvendy, 1998. Ergonomics in Manufacturing. 1st Edn., Engineering and Management Press, Norcross, Georgia.

Kong, Y.K. and B.D. Lowe, 2005b. Optimal cylindrical handle diameter for grip force tasks. Int. J. Ind. Ergon., 35: 495-507.

Kong, Y.K. and B.D. Lowe, 2005a. Evaluation of handle diameters and orientations in a maximum torque task. Int. J. Ind. Ergon., 35: 1073-1084.

Kong, Y.K., A. Freivalds and S.E. Kim, 2004. Evaluation of handles in a maximum gripping task. Ergonomics, 47: 1350-1364.

Kong, Y.K., B.D. Lowe, S.J. Lee and E.F. Krieg, 2007. Evaluation of handle design characteristics in a maximum screwdriving torque task. Ergonomics, 50: 1404-1418.

Kumar, S., 2008. Biomechanics in Ergonomics. 2nd Edn., CRC Press, Boca Raton.

Lee, J.W. and K. Rim, 1991. Measurement of finger joint angles and maximum finger forces during cylinder grip activity. J. Biomed. Eng., 13: 152-162.

Lima, M., L. Hes, R. Vasconcelos and J. Martins, 2005. FRICTORQ, Accessing fabric friction with a novel fabric surface tester. AUTEX Res. J., 5: 194-201.

Loi, 2012. Product Catalog: Knobs. Linp Omter International. http://www.omtertyxn.com/index.asp.

Longii, C., P.W. Conrad, E.A. Hall and S.L. Furler, 1970. Intrinsic-extrinsic muscle control of the hand in power grip and precision handling: An electromyographic study. J. Bone Joint Surg., 52: 853-867.

Magee, D.J., 2008. Orthopedic Physical Assessment. 5th Edn., Saunders Elsevier, St. Louis, Missouri.

Mathiowetz, V., C. Rennells and L. Donahoe, 1985. Effect of elbow position on grip and key pinch strength. J. Hand Surg., 10: 694-697.

McGorry, R.W., 2000. A system for the measurement of grip forces and applied moments during hand tool use. Applied Ergonomics, 32: 271-279.

Mital, A. and C. Channaveeraiah, 1988. Peak volitional torques for wrenches and screwdrivers. Int. J. Ind. Ergonom., 3: 41-64.

Moes, C.C.M. and I. Horvath, 1999. Ergonomics considerations for the conceptualization of the shape of body supports. Proceedings of the CIRP International Design Seminar, March 24-26, 1999, Enschede, The Netherlands, pp: 435-448.

Monroe, 2013. Monroe industrial knobs. http://catalog.monroeengineering.com/category/knobs.

Montoye, H.J. and J.A. Faulkner, 1964. Determination of the optimum setting of an adjustable grip dynamometer. Res. Q. Am. Assoc. Health Phys. Educ. Recreation, 35: 29-36.

Motawar, B., P. Hur and N.J. Seo, 2011. Roles of cutaneous sensation and gloves with different coeficients of friction on fall recovery during simulated ladder falls. Proceedings of the 35th Annual Meeting of the American Society of Biomechanics, August 10-13, 2011, Long Beach, California.

Ng, P.K. and A. Saptari, 2012. A review of shape and size considerations in pinch grips. Theoretical Issues Ergonomics Sci., 10.1080/1463922X.2012.729619

Ng, P.K., A. Saptari and J.A. Yeow, 2012. Synthesising the roles of torque and sensation in pinch force: A framework. Theoretical Issues Ergonomics Sci., 10.1080/1463922X.2012.691185

Ng, P.K., K.S. Jee, A. Saptari and J.X. Leau, 2013a. Familiarity with office equipment reduces human errors and accidents: A survey. Proceedings of the International Conference on Advances in Mechanical and Manufacturing Engineering, December 19-20, 2013, Kuala Lumpur, Malaysia.

Ng, P.K., K.X. Chai, S.L. Leh, M.C. Bee, Q.H. Boon and A. Saptari, 2013b. Applying clockwise and counterclockwise torque directions in pinch grips: A descriptive study. Proceedings of the 4th International Conference on Mechanical and Manufacturing Engineering, December 19-20, 2013, Bangi, Putrajaya, Malaysia.

Ng, P.K., M.C. Bee, A. Saptari and N.A. Mohamad, 2013c. A review of different pinch techniques. Theoretical Issues Ergonomics Sci., 10.1080/1463922X.2013.796539

Ng, P.K., M.C. Bee, Q.H. Boon, K.X. Chai, S.L. Leh and K.S. Jee, 2013d. Pinch techniques and their effects on pinch effort: A pilot study. Proceedings of the 4th International Conference on Mechanical and Manufacturing Engineering, December 19-20, 2013, Bangi, Putrajaya, Malaysia.

Ng, P.K., Q.H. Boon, K.X. Chai, S.L. Leh, M.C. Bee and A. Saptari, 2013e. The roles of shape and size in the pinch effort of screw knobs. Proceedings of the 4th International Conference on Mechanical and Manufacturing Engineering, December 19-20, 2013, Bangi, Putrajaya, Malaysia.

Ng, P.K., S.L. Leh, M.C. Bee, Q.H. Boon, K.X. Chai and K.S. Jee, 2013f. The Effects of different tactile sensations on pinch effort. Proceedings of the 4th International Conference on Mechanical and Manufacturing Engineering, December 19-20, 2013, Bangi, Putrajaya, Malaysia.

Nunnally, J. and I. Bernstein, 1994. Psychometric Theory. 3rd Edn., McGraw-Hill, New York, USA.

Petrofsky, J.S., C. Williams, G. Kamen and A.R. Lind, 1980. The effect of handgrip span on isometric exercise performance. Ergonomics, 23: 1129-1135.

Pheasant, S. and D. O'Neill, 1975. Performance in gripping and turning-A study in hand/handle effectiveness. Applied Ergonomics, 6: 205-208.

Pylatiuk, C., A. Kargov, S. Schulz and L. Doderlein, 2006. Distribution of grip force in three different functional prehension patterns. J. Med. Eng. Technol., 30: 176-182.

RSC, 2012. Reid supply company E-catalogue. Reid Supply Company. http://www.reidsupply.com.

Radhakrishnan, S. and M. Nagaravindra, 1993. Analysis of hand forces in health and disease during maximum isometric grasping of cylinders. Med. Biol. Eng. Comput., 31: 372-376.

Rock, K.M., R.P. Mikat and C. Foster, 2001. The effects of gloves on grip strength and three-point pinch. J. Hand Therapy, 14: 286-286.

Seo, N.J., T.J. Armstrong, J.A. Ashton-Miller and D.B. Chaffin, 2007. The effect of torque direction and cylindrical handle diameter on the coupling between the hand and a cylindrical handle. J. Biomech., 40: 3236-3243.

Seo, N.J. and T.J. Armstrong, 2008. Investigation of grip force, normal force, contact area, hand size and handle size for cylindrical handles. Human Factors, 50: 734-744.

Seo, N.J., T.J. Armstrong, D.B. Chaffin and J.A. Ashton-Miller, 2008a. Inward torque and High-friction handles can reduce required muscle efforts for torque generations. Human Factors, 50: 37-48.

Seo, N.J., T.J. Armstrong, D.B. Chaffin and J.A. Ashton-Miller, 2008b. The effect of handle friction and inward or outward torque on maximum axial push force. Hum. Factors, 50: 227-236.

Seo, N.J., J.K. Shim, A.K. Engel and L.R. Enders, 2011. Grip surface affects maximum pinch force. Human Factors, 53: 740-748.

Sesek, R.F., M. Khalighi, D.S. Bloswick, M. Anderson and R.P. Tuckett, 2007. Effects of prolonged wrist flexion on transmission of sensory information in carpal tunnel syndrome. J. Pain, 8: 137-151.

Shivers, C.L., G.A. Mirka and D.B. Kaber, 2002. Effect of grip span on lateral pinch grip strength. Human Factors, 44: 569-577.

Shock-Tek, 2013. Study: Hand injuries most prevalent. Shock-Tek LLC™. http://www.shocktek.com/OccupationalHandInjuries.pdf

Smith, R.O. and M.W. Benge, 1985. Pinch and grasp strength: Standardization of terminology and protocol. Am. J. Occup. Ther., 39: 531-535.

Swanson, A.B., I.B. Matev and G. de Groot, 1974. The strength of the hand. Inter-Clinic Inform. Bull., 13: 1-8.

Tanaka, M. and Y. Numazawa, 2004. Rating and valuation of human haptic sensation. Int. J. Applied Electromagnetics Mechanics, 19: 573-579.

WDS Component Parts, 2012. Hand knobs and thumb screws. http://goo.gl/9ANFyn.

Winco, J.W., 2011. Selecting the correct knob. J.W. Winco, Inc., http://www.jwwinco.com /engineeringtips/selectingcorrectknob.html.

Winco, J.W., 2012a. Ergonomic hand Knobs-with tapped insert. J.W. Winco, Inc., http://www.jwwinco.com /products/section8/veg/index.html.

Winco, J.W., 2012b. Ergonomic hand Knobs-with threaded stud. J.W. Winco, Inc., http://www.jwwinco.com /products/section8/vegs/index.html

Winco, J.W., 2012c. Hand Knobs-tapped or blind bore type. J.W. Winco, Inc., http://www.jwwinco.com /products/section8/gn5335/index.html.

Winco, J.W., 2012d. Quick release nine lobed hand knobs. J.W. Winco, Inc., http://www.jwwinco.com /products/section8/wn5335.5/index.html.

Yuan, C.K. and C.L. Kuo, 2006. Influence of hand grenade weight, shape and diameter on performance and subjective handling properties in relations to ergonomic design considerations. Applied Ergonomics, 37: 113-118.