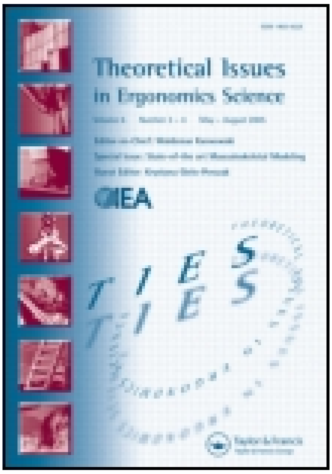

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Ergonomics aspects of knob designs: a literature review

Yue Hang Tan[a], Poh Kiat Ng[a], Adi Saptari[b] & Kian Siong Jee[a]
[a] Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, Bukit Beruang, 75450 Malacca, Malaysia
[b] Department of Manufacturing Management, Faculty of Manufacturing Engineering, Technical University of Malaysia, Hang Tuah Jaya, 76100 Durian Tunggal, Malacca, Malaysia
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Ergonomics aspects of knob designs: a literature review

Yue Hang Tan[a], Poh Kiat Ng[a]*, Adi Saptari[b] and Kian Siong Jee[a]

[a]*Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, Bukit Beruang, 75450 Malacca, Malaysia;* [b]*Department of Manufacturing Management, Faculty of Manufacturing Engineering, Technical University of Malaysia, Hang Tuah Jaya, 76100 Durian Tunggal, Malacca, Malaysia*

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Hand-related apparatus designs that fail to accommodate appropriate hand postures can cause hand-related musculoskeletal disorders. While there have been studies on the handling and design of various hand-related apparatus, little has been written on the ergonomics aspects of knob designs. The aim of this paper is to review various knob designs and their ergonomics aspects. The literature review suggests that gearshift knobs, door knobs, gas valve knobs, butterfly nuts and screw knobs are common knobs used for daily living activities. Other knobs like the convex, knurled, spherical, cone-shaped and ridged knob are often used for industrial-related applications. The ergonomics considerations identified in knobs include aesthetic attraction, position, torque requirement and shape-coding. This literature review can be used as groundwork for the development of ergonomics theory and hand-related studies. Engineers can use this literature review to identify certain ergonomics aspects in knobs to improve equipment designs, operating efficiency and working comfort.

Keywords: knob; shape; ergonomics aspects; literature review; design

1. Introduction

Many researchers have found that it is possible for critical factors such as highly repetitive hand motions, high pinch force exertions and awkward hand postures to cause injuries and musculoskeletal disorders (Villanueva, Dong, and Rempel 2007; Rock, Mikat, and Foster 2001; Burke, Main, and Freeman 1997; Rolian, Lieberman, and Zermeno 2011; Ng et al. 2013a; Ng et al. 2013b). In connection with the foregoing assertion, it was also found that even the design of common items and apparatus such as knobs, screw knobs, control handles and hand tools can affect the hand posture of individuals such that it leads to musculoskeletal disorders (Dong et al. 2007; Stevenson et al. 2000; Browne and O'Sullivan 2012; Peebles and Norris 2003; Jost and Tseng 1990).

There have also been other related studies on the handling and design of different hand-related apparatus (e.g. holding a phone, manipulating video game controls, swinging a baseball bat, playing ball games, holding a mug, holding a pen and typing on a keyboard) (Vatavu and Zaiti 2013; Kiefhaber 1996; Hsu et al. 2013). However, there appear to be few scholarly review articles that highlight or identify the important ergonomics aspects of various knob designs.

Hence, the aim of this study is to conduct a literature review of various knob designs and their ergonomics aspects. The literature review provides a collective anthology on

*Corresponding author. Email: pkng@mmu.edu.my

different knob designs and presents ideas on how different types of knobs can influence the postures of the human hand. It is useful as a basis for future research on ergonomic knob designs for various machines, hand tools and products.

2. General types of knobs

With today's highly developed technological devices, user interface design has improved dramatically to the extent of enabling even common designs such as knobs to be used in both simple and complex tasks (Schutte and Eklund 2005). Knobs have been widely used in adjustment applications, such as the precise adjusting application of a microscope in a laboratory (Sillanpaa, Nyberg, and Laippala 2003).

A knob is a subclass of rotary control which can involve continuous control knobs, selector knobs, ganged knobs and jog shuttles (Kwahk and Han 2002). Knobs (namely selector knobs and jog shuttles) usually have certain properties such as grids, legends and number of positions (Kwahk and Han 2002; Keogh, Morrison, and Barrett 2007).

Knob design can be generally grouped into two categories. One category involves the technical aspects of the design, which include the knob's mechanical or electrical details, while another involves the ergonomics considerations, which include the knob's aesthetic appearance, usability and comfortability (Schutte and Eklund 2005; Keogh, Morrison, and Barrett 2007). Schutte and Eklund (2005) also believe that users may select knobs based on factors such as the attractiveness (in terms of design/appearance), durability, safety, operability and comfortability.

A door lock consists of three basic mechanisms, which include the main body, the lever and the door knob (Tsai, Hsiao, and Hung 2006). Door knobs are designed to allow the user to twist and open (or close) the door (Lobb and Woods 2012). Knobs are also used in kitchen electrical appliances (as control knobs of cookers for example) (Pinto et al. 2000). The rotating control knobs on ovens are used to control temperature and timing (Chen and Jackovin 2004).

Knobs are also used on treadmills for controlling the resistance of the treadmill belt (Ciriello et al. 2010). The resistance, which is controlled by turning the knob, increases with a clockwise rotation and decreases with a counterclockwise rotation (Ciriello et al. 2010; Mathiowetz et al. 1985).

Gearshift knobs are knobs available in cars and manipulated by drivers (Schutte and Schuder 1997). A gearshift knob is perhaps one of the most obvious interior parts that would easily catch the visual attention of customers (You et al. 2006). Knobs are also used extensively in electric train control panels (Stevenson et al. 2000). Stevenson et al. (2000) believe that a spherical knob can allow the electric train driver to assume a more comfortable hand position while driving the train.

Since knobs are designed for precise control as stated by Schutte and Eklund (2005), knobs are also used in precision medical devices such as the endoscope (Browne and O'Sullivan 2012). Levin et al. (2000) mention that the accurate and handy characteristics of knobs make them suitable to be used as volume adjustment controls on radios and other types of stereos.

A washing machine is equipped with dial knobs for simple and efficient function controlling (Ha et al. 2009). Functions like wash mode, dry mode, wash time and water level can be selected using the control knob (Ha et al. 2009). The tactile sensation of the control knob for washing machines was studied by Kleiss (2008), who investigated the preferred sensation of the users when turning the knob.

Knobs are also used in the shower for water temperature control. According to Green and Kemp (2002), it appears that when a handle is attached on a knob, the turning operation for the knob becomes easier. Gas valve control knobs are invented for the convenience of the users who adjust the gas flow rate without directly accessing the gas valve (Harris and Miller 1985). Harris and Miller (1985) believe that it would be safer and more ergonomic for users to control the knob rather than the gas valve since users can easily adapt to the use of the knob's turning operation. Gas valve control knobs are economically produced and easily obtainable (Harris and Miller 1985).

Other types of commonly available knobs include circular knobs, ridge knobs, butterfly nuts and tap knobs (Peebles and Norris 2003). Knobs for furniture are designed for handling purposes and fixture appearance (Matijevic 2008). Screw knobs are used to join/connect objects together with an adjustable screw mechanism (Shih and Ou 2005; Keogh, Morrison, and Barrett 2007; Shivers, Mirka, and Kaber 2002) and were frequently used in the intravenous stand designed by Jost and Tseng (1990), who designed the pole to be adjustable according to the patient's height.

Various types of knobs are used on the control panel of aircrafts (Stanton et al. 2009). The design of knobs in an aircraft is important as it can potentially evade the occurrence of human errors (Stanton et al. 2009). The use of knobs can be found on consumer electronics products as well, such as telecommunication devices and home appliances (Kwahk and Han 2002). These knobs are considered as the interface components of consumer devices, and their usability has become an important factor to gaining acceptance in the market (Kwahk and Han 2002).

Knobs are used for height adjustment in office chairs as well (Groenesteijn et al. 2009). The difficulty of height adjustment in office chairs using knobs has also been investigated by some researchers, as this factor is one of the design considerations that improves the ergonomics and comfort of chairs (Groenesteijn et al. 2009).

3. Ergonomics factors

Today, knobs do not only act as input control devices, but are also ergonomically designed to adapt with the user's convenience. Knobs, which are designed ergonomically, can prevent accidents from happening, improve working efficiency and avoid muscle injuries. The following subsections present several ergonomics factors considered in knob designs and other research pertaining to knobs.

3.1. Human perception and hand activities

Different types of knob manipulation have been studied in relation to actions that involve pushing, pulling and turning (Browne and O'Sullivan 2012). However, improper handling and excessive repetition in knob manipulation can cause injury to the hands (Browne and O'Sullivan 2012).

Certain factors, such as finger push strength, pinch-pull strength, hand grip strength, opening strength, wrist-twisting strength and push-pull strength, are often considered so as to conform to the ergonomics aspects of the design (Ng et al. 2014; Peebles and Norris 2003). Peebles and Norris (2003) discovered that turning torque can be increased by adding knurls or ridges on the object since the grip is improved (knobs or lids).

Studies have also found that knurling has no effect on torque when the object's diameter is smaller than 86 mm (Peebles and Norris 2003; Nagashima and Konz 1986; Imrhan and Loo 2007). Imrhan and Jenkins (1999) state that knurled handle torques are larger than smooth handle torques by approximately 1.15 times.

Stereotype control behaviour is the relationship between the control movements made by users and their effects on the display based on the instincts of the users (Chan, Shum, and Poon 2002). According to Chan, Shum, and Poon (2002), a rotary control with a linear display is commonly used in many devices and equipment in the industry.

There are a few major stereotype principles that have been suggested for rotary control and linear display combinations, which include the Warrick's principle, clockwise-for-right principle, clockwise-for-increase principle and the scale side principle (Chan, Shum, and Poon 2002). A short adjustment time, where the control and display interfaces become compatible with each other, should preferably be achieved (Chan, Shum, and Poon 2002). Figure 1 presents a pictorial idea of the different types of common knobs.

3.2. *Ergonomic knobs*

In industries, such as the automotive industry, ergonomists and functional designers have been working on improving control and display systems in order to minimise and prevent human error that often cause accidents to happen (Schutte and Eklund 2005; Kim et al. 2011; Ng et al. 2013e). It has been found that around 75% of all accidents are associated with human errors (Stanton et al. 2009). Researchers believe that the ergonomic design of the control interface can also reduce the stress and tiredness of drivers (Schutte and Eklund 2005).

Since the ergonomics properties of mechanical knobs are highly important in modern designs, many companies are putting up more effort in designing comfortable and user-friendly knobs (Ha et al. 2009). For instance, the dial knob of a washing machine is designed according to some design considerations like torque profile, aesthetical appearance, functionality, physical properties and sound effects (Ha et al. 2009).

The visual appearance and ergonomics aspects of a vehicle's interior design are one of the main concerns of the customers (You et al. 2006). The material used in a knob therefore plays a crucial role, as customers tend to judge the quality of the knob by its appearance and tactile sensation (You et al. 2006; Ng et al. 2013f). Researchers have also found that the softness, shininess and surface texture of knobs are factors related with the appearance judgment of customers (You et al. 2006; Ryu et al. 2003; Tanoue, Ishizaka, and Nagamachi 1997).

Certain ergonomic control knobs are designed with force feedback features to provide torque resistance and physical sensation to the user (Levin et al. 2000). The force feedback features are controlled by integrated electrical motors and microprocessors that allow different kinds of tactile sensation to be programmed accordingly (Levin et al. 2000). Some control knobs are also designed with multiple degrees of freedom, which enable rotary, transverse and linear directional movements (Levin et al. 2000). The rotary movements allow knobs to be rotated about the rotating axis, while the transverse movements (perpendicular to the axis) and the linear movements allow the knobs to be pushed or pulled (Levin et al. 2000).

Normally, an index line or mark is indicated on a knob when the position of a rotary control knob is to be discerned (Kroemer, Kroemer, and Kroemer-Elbert 2001). In consideration of these factors, Harris and Miller (1985) designed a gas valve knob which includes an index mark and pointer for safety and ease of identification, so as to display the angular displacement of the gas valve knobs to the user.

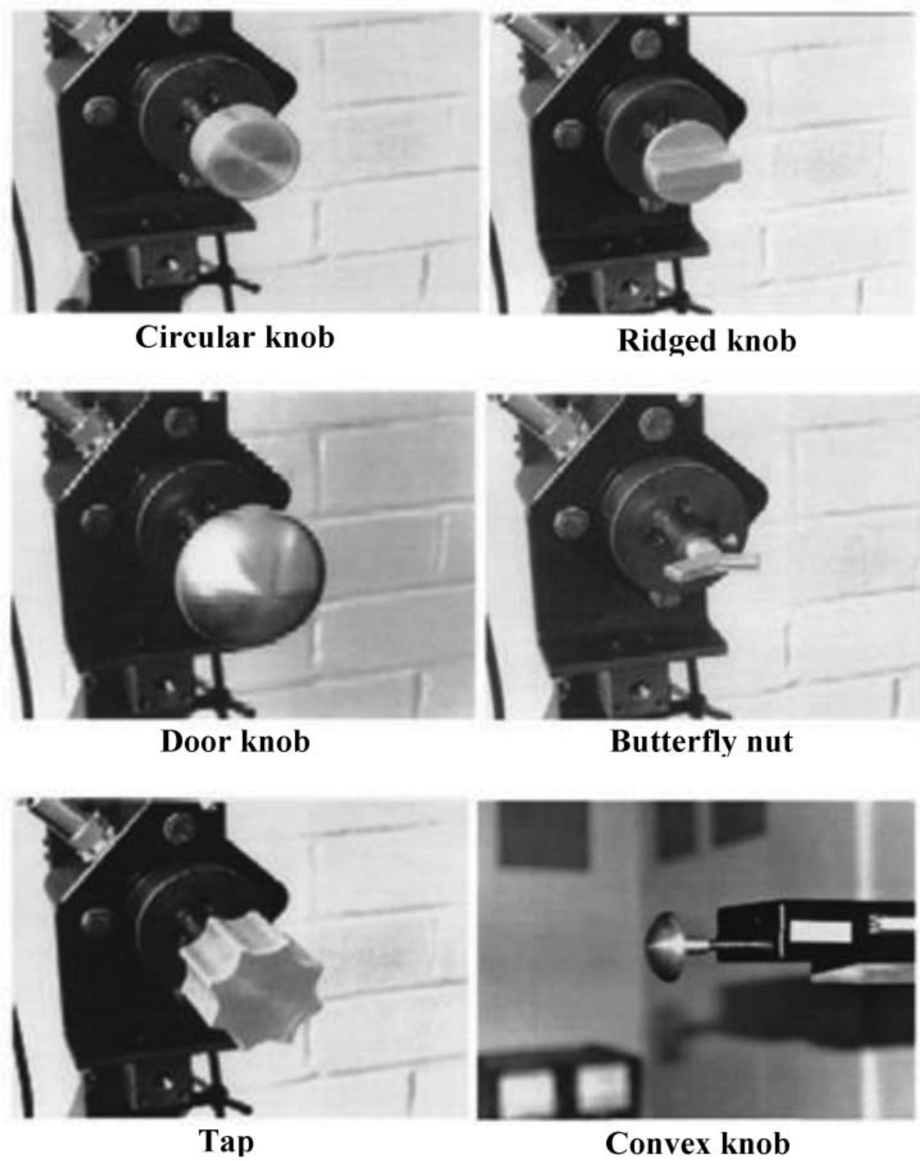

Figure 1. Different types of common knobs (Peebles and Norris 2003).

Since there can be multiple knobs of different functions available on a control panel, knobs need to be shape-coded for safety purposes and in order to reduce operational errors (Burgess-Limerick et al. 2010). Researchers have discovered that 5% of coal mine accidents were caused by control activation errors on bolting machines (Burgess-Limerick et al. 2010; Helander, Krohn, and Curtin 1983). Shape-coding can facilitate the identification of the knobs and allow them to be differentiated easily by operators according to shape, size, operation mode, labelling and colour (Kroemer, Kroemer, and Kroemer-Elbert 2001; Ng et al. 2013c; Ng and Saptari 2012).

The ergonomic design of control knobs has been an emphasis of designers for many years (Kleiss 2008). According to researchers, in order to idealise the ergonomic design of a particular knob, the size and shape of the knob are crucial factors to be considered (Woodson, Tillman, and Tillman 1992; Kleiss 2008; Amaral et al. 2013).

Studies show that elderly individuals of 65 years and above can only exert a capacity of 75% of the strength and endurance that they were able to exert in their younger years (<30 years old) (Shaheen and Niemeier 2001; Haigh 1993). Lee and Su (2008) postulate that the difficulty of the adjustment of control knobs is determined by the size and tolerance of the knob. However, Kroemer, Kroemer, and Kroemer-Elbert (2001) opine that if the turning resistance is low and the knob can be easily operated, the size of the knob is inconsequential. On the other hand, if the space is constrained, the knobs are required to be small and with low turning resistance to allow the user to manipulate it easily (Kroemer, Kroemer, and Kroemer-Elbert 2001).

The function of a knob is often given more attention to rather than the sensory quality of the knob, as designers generally do not consider it to be a critical factor to improve for optimised performance (Kleiss 2008). It was found that about 58% of elderly people obtain some form of disability in control and sensation when manipulating knobs (Shaheen and Niemeier 2001). A secure sensation is often one of the factors that should be considered, especially in knob designs that emphasise on providing a smooth tactile experience to knob users (Kleiss 2008). Beside this, the compatibility of control knobs with display devices is highly important for the reduction in human error and response time (Chan, Shum, and Poon 2002).

Kroemer, Kroemer, and Kroemer-Elbert (2001) suggest that continuous knobs should be considered in machine design if little turning torque and fine adjustments are required. Kroemer, Kroemer, and Kroemer-Elbert (2001) however explain that the knob position should be set in such a way that it is not affected by vibration or involuntary movements. In reflection of the abovementioned considerations, Bull (1987) designed a control knob with a push–pull mechanism, where the control knob was required to be pushed or pulled in order to engage. This prevented inadvertent and accidental adjustments to the device.

In summary, the ergonomics considerations incorporated in knob designs are useful based on several aspects. Knobs with sensory feedback capabilities (such as haptic knobs) can aid users to perceive input levels and influence their usability and comfort when manipulating a device. For a functional knob design, the operating degrees of freedom (pushing, pulling and turning) need to be considered so that the knob is of good quality, reliable and user-friendly. The appearance and choice of materials for the knob are also important in order to provide a quality tactile experience for the users.

Knobs, which are attached to industrial equipment and machines, need to consider certain surface temperature changes that may be caused by the heat transferred from the machines. This forethought is important given that some knob surfaces may get too hot and uncomfortable for handling and operation, and even lead to injuries. The surface of these knobs requires the use of heat resistant materials to ensure the comfort and safety of the user.

Certain knob designs are highly beneficial to the users for shape-coding, indication, compatibility and positioning. Knobs, which are built with appropriate friction and torque requirements (such as knurled knobs), are much easier to be operated (Swanson, Matev, and Groot 1970; Ng et al. 2013d; Ng, Saptari, and Yeow 2012). Safety features such as push–pull locking mechanisms are also available on some knobs to prevent accidental activations of input controls. Apart from that, in order to accommodate more precise adjustments, a continuous knob design would be preferable.

Tables 1 and 2 both show a brief summary of different types of knobs and the related ergonomics studies that have been previously carried out by researchers.

4. Theoretical implications

The compilation of this literature review on knobs can be a good foundation for future research on knobs, pinch techniques and related studies on musculoskeletal disorders. The knowledge on knobs can also be a basis for developing theories in union with other biomechanical studies. This literature review can also serve as preliminary groundwork for designers and engineers to design and build creative and unique designs that utilise knobs.

As an example, researchers who conduct studies on the forearm posture can relate their research with the manipulation of knobs and invent new guidelines to allow more comfortable and user-friendly knob operations that potentially reduce the risks of work-related injuries with inappropriate forearm postures. Beside this, a new avenue for future studies is also created through this literature review with the aim to encourage researchers from various disciplines to conduct more investigations on the research related to knobs.

5. Practical implications

With this anthology of various knob designs, an improved knob design can be developed by designers and engineers. The comfortability and working efficiency while manipulating knobs can be improved and optimised radically with the development of an ergonomic knob. These aspects improve their selling points and attract the attention of buyers who often look into the aesthetics and user-friendliness of a design.

An ergonomic knob can also help reduce the occurrence of human errors with its convenience of use. This can potentially improve the safety level of the workplace. Lesser workplace accidents and errors will eventually lead to healthcare cost reduction, increased productivity and improved product quality. Workers will be able to experience an improved quality of life and higher job satisfaction with a safer working environment.

6. Directions for future research

For future research, it is proposed that an empirical study is carried out to investigate the user preference on knobs among manual workers. An empirical study will help researchers to directly understand the perspectives of manual workers and how they actually visualise the design of an ergonomic knob. More quantitative findings are also required in order to support the substantiations of this literature review.

Biomechanical instruments can also be used to collect strength data from manual workers who often use knobs while operating their equipment. For instance, force sensors can be attached to their fingers to measure the feedback of the pinch force when the worker operates a knob. Using statistical analyses, researchers can conduct hypothesis tests and identify the effects of certain knob designs on the biomechanical pinch force of a human hand.

Safety guidelines can also be developed from the results of observation research and statistical analyses. These guidelines will be useful for manual workers. With the correct understanding of knob designs, pinch force exertion, pinch posture and handling method, manual workers can execute their tasks safely and more efficiently. With these guidelines,

Table 1. Summary of different types of knobs.

No.	Type of knob	Description	Reference
1	Ganged knob	Used to control electrical circuits	(Kwahk and Han 2002)
2	Jog shuttle	A type of knob to jog or shuttle for making selection	(Kwahk and Han 2002)
3	Door knob	Used to twist and open or close the door	(Lobb and Woods 2012)
4	Control knob	Used to control electrical appliances, like cookers, ovens and treadmills	(Pinto et al. 2000; Chen and Jackovin 2004; Ciriello et al. 2010)
5	Gearshift knob	One of the most common interior parts that drivers often make contact with	(Schutte and Schuder 1997; You et al. 2006)
6	Endoscope knob	Used by medical practitioners to allow the precise adjustments of the endoscope	(Browne and O'Sullivan 2012)
7	Gas valve knob	Used for safer and easier adjustments of gas flow rate	(Harris and Miller 1985)
8	Furniture knob	Used for handling and cosmetic purposes	(Matijevic 2008)
9	Butterfly nut	A threaded nut with wing-like projections	(Peebles and Norris 2003)
10	Tap	A star shaped knob. Also known as a five-lobes knob.	(Peebles and Norris 2003)
11	Screw knob	Used to join two poles or objects together.	(Jost and Tseng 1990)
12	Convex knob	A knob with a protrusion surface.	(Peebles and Norris 2003)
13	Knurled knob	A knob with series of small ridges or grooves on the surface.	(Kroemer, Kroemer, and Kroemer-Elbert 2001)
14	Spherical knob	A knob that assumes the shape of a sphere.	(Kroemer, Kroemer, and Kroemer-Elbert 2001)
15	Cone-shape knob	A knob that assumes the shape of a cone.	(Kroemer, Kroemer, and Kroemer-Elbert 2001)
16	Circular knob	A knob that assumes the shape of a circle or cylinder.	(Peebles and Norris 2003)
17	Ridged knob	A knob with a rectangular and elevated shape on top of it.	(Peebles and Norris 2003)

Table 2. Summary of the ergonomics studies on knobs.

No.	Key points	Description	Reference
1	Haptic knob	Able to produce programmable haptic effects.	(Giraud, Amberg, and Lemaire-Semail 2013)
2	Knob's aesthetic appearance and ergonomics	Aesthetic appearance has impact on buying decision.	(Schutte and Eklund 2005)
3	Ergonomics consideration for gearshift knob	To make the control interface suit the driver better.	(Schutte and Schuder 1997)
4	Pushing, pulling, turning of knobs	Various control actions consideration for designing knobs.	(Browne and O'Sullivan 2012)
5	Surface temperature of knobs	Surface temperature affects the comfortability or holdability of knobs.	(Greenbaum and Paterson 1996)
6	Positioning of knob	To avoid guessing and confusion of the users.	(Chan and Chan 2006; Chan and Chan 2007)
7	Comfortability of knobs	Consideration of torque profile, notch, visual appearance, functionality, physical properties, and sound effects.	(Ha et al. 2009)
8	Material selection of knobs	Material types reflect the quality of the control knobs.	(You et al. 2006)
9	Various strengths considerations	Finger push strength, pinch-pull strength, hand grip strength, wrist-twisting strength, opening strength, push and pull strength.	(Peebles and Norris 2003)
10	Knurling on knobs	Knurling increase friction coefficient between knobs and fingers.	(Peebles and Norris 2003; Imrhan and Jenkins 1999)
11	Shape coding of knobs	Ease the differentiation of knobs.	(Burgess-Limerick et al. 2010; Kroemer, Kroemer, and Kroemer-Elbert 2001)
12	Size, shape, and torque requirement for knobs	Important factors in designing an ergonomic knob.	(Kleiss 2008; Lee and Su 2008; Kroemer, Kroemer, and Kroemer-Elbert 2001)
13	Sensory quality of knob	Pleasantness of tactile experience.	(Kleiss 2008)
14	Compatibility of knob and output device	Simplicity of the relationship between input knob and the output device.	(Chan, Shum, and Poon 2002)
15	Control knobs degrees of freedom	For example rotary, transverse and linear.	(Levin et al. 2000)
16	Knob's pointer	Indication of the angular displacement of knobs for safe adjustment.	(Harris and Miller 1985; Kroemer, Kroemer, and Kroemer-Elbert 2001)
17	Push-pull locking mechanism for rotary control knob	To prevent inattentive adjustment of the valve.	(Bull 1987)
18	Continuous knob for fine adjustment	Little force and precise adjustments can be performed.	(Kroemer, Kroemer, and Kroemer-Elbert 2001)

the knowledge on knob-handling safety will eventually become a norm among industrial workers and motivate designers and ergonomists to design more user-friendly knobs.

7. Conclusion

Generally, this literature review provides a summary on the variation of knobs that are available in the industry and everyday life. It appears that knobs are used differently in various applications. Their shapes and designs serve a variety of purposes. This literature review suggests that the biomechanics of hand movements and natural consciousness of humans are major elements that contribute to the design of an ergonomic knob.

Designers should develop an apperception on the importance of ergonomics considerations when designing knobs. The ergonomics considerations for an ergonomic knob can include the comfortability, usability and aesthetics of the design. Since hand-related musculoskeletal disorders are affected by commonly assumed working postures, it is essential for ergonomists, designers and engineers to consider the position of their knob designs in regards to the working posture and handling position of the equipment or apparatus.

Relevance to ergonomics theory

This literature review serves as a reference for designers to improve their designs such that inappropriate and less ergonomic working postures can be avoided. Considering ergonomics aspects in knob designs reduces human error and risks of workplace accidents. Ergonomics researchers can also use this literature review as a guideline for future hand-related designs and research.

About the authors

Yue Hang Tan, BEng, is a graduate research assistant from the Faculty of Engineering and Technology, Multimedia University, Malaysia. He also obtained his bachelor's degree in mechanical engineering from Multimedia University, Malaysia. He is currently doing his masters in engineering science at Multimedia University, Malaysia. His research interests include ergonomics, biomechanics and engineering design.

Poh Kiat Ng, MEng, is a senior lecturer from the Faculty of Engineering and Technology, Multimedia University, Malaysia. He is also a PhD candidate at the Technical University of Malaysia. Prior to being an academician, he has worked in Infineon Technologies and National Semiconductor for several years as a manufacturing and process engineer. His research interests include ergonomics, biomechanics, manufacturing management, concurrent engineering and quality management.

Adi Saptari, PhD, is a professor from the Faculty of Manufacturing Engineering, Technical University of Malaysia. He is also the Head of the Department of Manufacturing Management. His research interests include ergonomics, operations research and technology management.

Kian Siong Jee, MSc, is a senior lecturer at the Faculty of Engineering and Technology, Multimedia University, Malaysia. His research interests include manufacturing technology, manufacturing systems, manufacturing management, materials engineering, maintenance engineering, green technology, quality management, engineering education and knowledge management.

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