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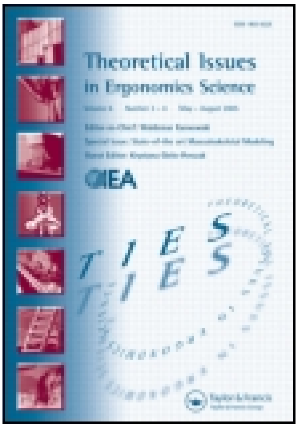

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REVIEW ARTICLE

A review of shape and size considerations in pinch grips

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In handgrip-related studies, it has been theorised that modifying the design of object shapes and sizes to accommodate the hand can reduce risks of cumulative trauma disorders (CTDs). However, there appears to be a lack of theoretical groundwork to support this premise in the area of pinch grip research. Therefore, this article aims to provide a review of shape and size considerations in pinch grips. The literature reviews were first conducted individually on shape, size and pinch grip factors, followed by the development of a literature summary based on the theoretical connections among shape, size and pinch grips. Though further studies are still required, this review has provided fundamental knowledge on possible theoretical connections among shape, size and pinch grip factors. These preliminary efforts shed light on potential mechanisms that explain how shape and size can influence pinch grips towards preventing CTDs and maximising the human performance.

Keywords: shape; size; pinch grip; cumulative trauma disorder; review

1. Introduction

Tasks that require pinch grips are commonly seen in many manufacturing industries from the design of small electronic parts to the assembly of large machinery (Eksioglu *et al.* 1996). Pinch grips are often used for high-precision tasks, such as connecting/disconnecting wires, assembling small electronic parts and adjusting controller knobs.

However, according to Ellis *et al.* (2004), the excessive use of pinch grips highly affects the risks of cumulative trauma disorders (CTDs). Both high- and low-pinch grip exertions have been related to fatigue, discomfort, injury and the development of various hand-related CTDs in industrial populations (Shivers *et al.* 2002, Ng *et al.* 2012).

In association with the above-mentioned predicaments, it is also known that changes in the shape and size of gripped objects can somehow affect their handling properties (Grant *et al.* 1992, Edgren *et al.* 2004, Yuan and Kuo 2006, Seo and Armstrong 2008). By understanding this proposition, it may be plausible to somehow modify the design of object shapes and sizes to accommodate handgrips and reduce risks of CTDs. However, it appears that there is a lack of the literature support to uphold this proposition in the area of pinch grip studies.

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Thus, the aim of this article is to conduct a review of shape and size considerations in pinch grips. For this review, a literature survey is first conducted on shape, size and pinch grips to better understand the individual context of their definitions and research findings. A literature summary is then developed on the relations among shape, size and pinch grips to identify important theoretical combinations for future research considerations.

2. Shape

Pinching techniques may vary depending on the way the shape of a pinched object is designed. The shape of an object is one of the essential criteria in hand tool designs to reduce stress on the hand muscles and finger tendons during tool use (Kong and Lowe 2005a).

Different object shape designs can primarily influence their handling properties (Yuan and Kuo 2006). According to Yuan and Kuo (2006), ball-shaped objects have better handling properties than the oval shape ones since people are naturally familiar with the techniques involved in handling sports-ball type shapes.

A number of studies proposed that the grip strategies applied by humans are based on external features, such as the shape and pliancy of the gripped object (Napier 1956, Landsmeer 1962, Elliott and Connolly 1984, Johansson and Westling 1984, Cutkosky 1989, Butterworth and Hopkins 1993, Gentilucci 2002, Santello *et al.* 2002, Wong and Whishaw 2004). For instance, the requirements to position the thumb relative to the index finger with an accurate direction of a resulting pinch force are influenced by the shape of the gripped object (Smaby *et al.* 2002, 2004).

Choi (2008) developed a three-dimensional kinematic model of the hand for predicting the hand posture of grasping a range of objects with varying shapes and sizes, also with an aid of a contact algorithm. Grieshaber *et al.* (2009) conducted a study on a technique to measure hand space envelopes of hose insertion tasks of different insertion methods. They found that although this measurement technique is useful for dynamic tasks, it is also not easily applied to other object shapes and sizes.

Besides that, Bae and Armstrong (2011) developed a model that describes human finger motion that simulates reach to grasp actions for selected objects and tasks. However, since only the flexion and extension of finger joints were examined, prediction of the thumb's carpometacarpal and metacarpophalangeal joints were not completely precise because of the palm arch, especially for grasping non-cylindrical work objects such as spherical shapes (Sangole and Levin 2008).

It is also sometimes difficult to conduct studies on several types of objects that have various textures or irregular shapes since every individual has different kinds of skin conditions (Smaby *et al.* 2004). Dry skin, for example, can lack the rough rugation pattern that assists an individual's grip (Silver *et al.* 1991, Smaby *et al.* 2004).

3. Size

A size of an object can be defined as the relative extent of the object or the object's overall dimensions or physical magnitude (Merriam-Webster 2011, Oxford 2011). Understanding the biodynamic response of a grip based on the size of an object is of critical importance for safety and musculoskeletal health reasons (Aldien *et al.* 2005).

A size of an object can affect the contact area where it is gripped. According to some researchers, the contact area decreases as the gripped object's size increases (Grant *et al.*

1992, Edgren *et al*. 2004, Seo and Armstrong 2008). This phenomenon is due to the lack of skin deformation on the palmar side of the hand which results in a reduced contact area of grip (Bobjer *et al*. 1993, Welcome *et al*. 2004, Seo and Armstrong 2008).

When gripping, forces are concentrated on the fingertips, which can cause the middle and proximal phalanges to lift off as the distal interphalangeal joint rotates, thus reducing the total contact area (Amis 1987, Lee and Rim 1991, Gurram *et al*. 1993, 1995, Radhakrishnan and Nagaravindra 1993, Kong *et al*. 2004, 2007, Kong and Lowe 2005a, b, Pylatiuk *et al*. 2006, Seo *et al*. 2007).

Besides that, it was also found that grip force reduces as the size of a gripped object increases (Grant *et al*. 1992, Edgren *et al*. 2004, Seo and Armstrong 2008). This is because when a gripped object's size is larger, the fingers open more and the moment arms for the finger flexor muscles decrease, thus causing a reduction in grip forces (An *et al*. 1979, 1983, Fowler *et al*. 2001, Seo and Armstrong 2008).

In addition, the contact area of a gripped object reduces as its size decreases (Pheasant and O'Neill 1975, Yakou *et al*. 1997, Welcome *et al*. 2004). This is due to the reduction of the available handle surface area (Pheasant and O'Neill 1975, Rohles *et al*. 1983, Yakou *et al*. 1997, Seo and Armstrong 2008). When gripping a small object, the finger flexion creates folds in the skin and results in a reduced contact with the object (Seo and Armstrong 2008).

In lifting research, the size of an object may affect the maximum acceptable weight of load, maximum acceptable weights of lifting, energy expenditure and spinal stresses (Ayoub and Mital 1989, Ciriello 2003, 2007, Jung and Jung 2010). Also, the size of tool handles often has a substantial effect on the biomechanical, physiological and perceived stress of the worker (Jung and Jung 2010).

When gripping a tool handle, an irregular distribution of forces at the hand surface varies significantly with different object sizes (Gurram *et al*. 1995). Gripping a large object may encourage individuals to apply grip force over the entire hand surface in contact with the object including the fingertips, which results in relatively higher pressure in the lateral side of the palm even when a push force is absent (Aldien *et al*. 2005).

4. Pinch grip

A pinch grip is defined as an act of gripping an object between the thumb and the finger (Trew and Everett 2005). The muscles that contribute to pinch grips include both the intrinsic and extrinsic musculatures of the hand and forearm (Dempsey and Ayoub 1996). While a handgrip reflects the gross power of the hand, a pinch grip is a determinant of thumb function (Lau and Ip 2006).

Whenever a unilateral hand activity is mandatory for workers, a strong pinch grip may be required (Lau and Ip 2006). Evaluation methods on pinch strength with respect to the arm, wrist postures, pinch spans and contact surface orientations have been investigated thoroughly for researchers to understand the capacities and limitations of pinch grips (Woody and Mathioweitz 1988, Hallbeck and McMullin 1993, Imrhan and Rahman 1995, Heffernan and Freivalds 2000).

Safety margins were also developed to avoid the overestimation of pinch grip capabilities (Seo 2009). Some researchers have also developed a theoretical framework that potentially explains the preliminary roles of torque and sensation in pinch force to enrich the knowledge on pinch force levels for reduced injury risks (Ng *et al*. 2012). While this framework applies for hard objects, it may need some consideration in addition to this if the objects are soft or easily damaged by additional applied forces.

Researchers also believe that rapid pinching movements made by machine operators can cause carpal tunnel syndrome and tenosynovitis (Sokas *et al.* 1989, Ellis *et al.* 2004). According to Keir *et al.* (1998), repetitive low-force pinch grips can cause more pressure on the carpal tunnel, which if prolonged, can lead to carpal tunnel syndrome.

However, since the force level of pinch grips can depend on the strength, control and posture of proximal arm joints, further study is needed on factors related to pinch grips such as pinch openings, force location, force direction and proximal joint control requirements (Murray *et al.* 2002, Smaby *et al.* 2004).

5. Development of the literature summary

Based on the literature review, a literature summary regarding the connections among shape, size and pinch grips was developed (Table 1). The subsequent sections provide detailed explanations on the summary developed.

5.1. *Shape considerations in pinch grip design criteria*

If the shape factor is an important consideration for tool designs to ensure an optimised performance in handgrips (Kong and Lowe 2005a), it should also be an important consideration for designs that implement pinch grips. A possible reason for this may be because grip strategies tend to change based on the shape and pliancy of gripped objects (Napier 1956, Landsmeer 1962, Elliott and Connolly 1984, Johansson and Westling 1984, Cutkosky 1989, Butterworth and Hopkins 1993, Gentilucci 2002, Santello *et al.* 2002, Wong and Whishaw 2004).

It can therefore be somewhat theorised that the modification of an object's shape is important to accommodate an individual's pinch grip strategy. Designing object shapes to conform appropriately to pinch grips may help prevent muscle and tendon injuries.

For example, in an application where a worker is required to pinch a key using a lateral pinch technique, it would be appropriate for the designer to modify the design of the key to accommodate the structure of the lateral pinch technique based on the position and shape of the user's phalanges.

5.2. *Shape and size considerations in pinch grip capacities*

The understanding of pinch grip capacities can be seen in a different light with the consideration of shape and size in assessments that involve pinch force measurements with respect to the arm, posture, pinch span and contact surface orientation (Woody and Mathioweitz 1988, Hallbeck and McMullin 1993, Imrhan and Rahman 1995, Heffernan and Freivalds 2000). It is important to understand the biodynamic responses of pinch grips based on both the shape and size in order to avoid pinch force overestimations from the intrinsic and extrinsic muscles of the hand (Dempsey and Ayoub 1996, Aldien *et al.* 2005, Bae and Armstrong 2011).

Although it is not easy to evaluate the importance of the shape and size criteria in handgrips due to dynamic tasks (Aldien *et al.* 2005) and different skin conditions (Silver *et al.* 1991, Smaby *et al.* 2004), it may be simpler in the case of pinch grips. The reason for this is because pinch grips will only involve the thumb and other fingers but not the palm

Table 1. The literature summary on shape, size and pinch grip factors.

No.	Category	Explanation	Shape and size references	Pinch grip references
1	Shape considerations in pinch grip design criteria	Designing object shapes that conform appropriately to pinch grips may help prevent muscle and tendon injuries while pinching	Kong and Lowe (2005a), Yuan and Kuo (2006), Butterworth and Hopkins (1993), Cutkosky (1989), Elliott and Connolly (1984), Gentilucci (2002), Johansson and Westling (1984), Landsmeer (1962), Napier (1956), Santello *et al*. (2002), Wong and Whishaw (2004), and Smaby *et al*. (2002, 2004)	Trew and Everett (2005), Lau and Ip (2006), Dempsey and Ayoub (1996) and Lau and Ip (2006)
2	Shape and size considerations in pinch grip capacities	Understanding pinch grip capacities by pinching objects of various shapes and sizes may decrease potential hand injuries	Choi (2008), Grieshaber *et al*. (2009), Bae and Armstrong (2011), Sangole and Levin (2008), Smaby *et al*. (2004), Silver *et al*. (1991), Merriam-Webster (2011), Oxford (2011) and Aldien *et al*. (2005)	Dempsey and Ayoub (1996), Lau and Ip (2006), Hallbeck and McMullin (1993), Heffernan and Freivalds (2000), Imrhan and Rahman (1995), Woody and Mathioweitz (1988), Seo (2009), Murray *et al*. (2002) and Smaby *et al*. (2004)
3	Size considerations in pinch grip spans	Investigating pinch grip spans for various object sizes may widen the applicability of the pinch grip safety margins developed	Edgren *et al*. (2004), Grant *et al*. (1992), Seo and Armstrong (2008), Bobjer *et al*. (1993), Welcome *et al*. (2004), Amis (1987), Gurram *et al*. (1993, 1995), Kong *et al*. (2004, 2007), Kong and Lowe (2005a, b), Lee and Rim (1991), Pylatiuk *et al*. (2006), Radhakrishnan and Nagaravindra (1993) and Seo *et al*. (2007)	Trew and Everett (2005), Dempsey and Ayoub (1996), Lau and Ip (2006) and Seo (2009)

(*continued*)

Table 1. Continued.

No.	Category	Explanation	Shape and size references	Pinch grip references
4	Size considerations in pinch force changes	Examining pinch force changes for various object sizes may help improve force control and understanding of strength requirements	Edgren *et al*. (2004), Grant *et al*. (1992), Seo and Armstrong (2008), An *et al*. (1979, 1983), Fowler *et al*. (2001), Seo and Armstrong (2008), Pheasant and O'Neill (1975), Welcome *et al*. (2004), Yakou *et al*. (1997), Rohles *et al*. (1983), Gurram *et al*. (1995) and Aldien *et al*. (2005)	Trew and Everett (2005), Lau and Ip (2006), Murray *et al*. (2002) and Smaby *et al*. (2004)
5	Size considerations in repetitive pinching	Understanding the contribution of size in repetitive pinching may help broaden theories on potential causes of hand-related CTDs	Ayoub and Mital (1989), Ciriello (2003, 2007) and Jung and Jung (2010)	Ellis *et al*. (2004), Sokas *et al*. (1989), Arvidsson *et al*. (2003), Longo *et al*. (2002) and Keir *et al*. (1998)

arc (Sangole and Levin 2008). The above-mentioned justifications posit that the consideration of the shape and size factor in designs for pinch grips can improve the theoretical versatility and understanding on pinch grip capacities.

5.3. *Size considerations in pinch grip spans*

In handgrip applications, gripping large objects causes concentration of forces on the fingertips and proximal phalanges to be raised up from contact, leading to total contact area reduction (Amis 1987, Lee and Rim 1991, Gurram *et al.* 1993, 1995, Radhakrishnan and Nagaravindra 1993, Kong *et al.* 2004, 2007, Kong and Lowe 2005a, b, Pylatiuk *et al.* 2006, Seo *et al.* 2007). However, in the case of pinching, the pinch span increases as the object's size increase.

The aforementioned proposition suggests that it is important to consider the size in pinch grip designs because excessively large pinch grip spans can cause overstretching of tendons (Belcher 2012) and damage the intrinsic and extrinsic musculature of the hand and forearm (Dempsey and Ayoub 1996).

Also, by combining the exceptionally strong pinch grips of manual workers (Lau and Ip 2006) with different object sizes, existing safety margins on pinch grips (Seo 2009) can be further optimised to accommodate different pinch spans. This idea is important for the research and development of pinch grips and knob designs as an individual's pinch span may reflect on the amount of pinch force he/she can generate.

5.4. *Size considerations in pinch force changes*

Gripping large objects can cause grip forces to reduce due to the decrease in finger flexor moment arms (An *et al.* 1979, 1983, Grant *et al.* 1992, Fowler *et al.* 2001, Edgren *et al.* 2004, Seo and Armstrong 2008). Contrarily, gripping small objects do not cause grip forces to increase due to the creation of folds in the skin from the finger flexion (Pheasant and O'Neill 1975, Rohles *et al.* 1983, Yakou *et al.* 1997, Welcome *et al.* 2004, Seo and Armstrong 2008). These mechanisms can perhaps be reflected on pinch forces since pinching involves the functions of the thumb and fingers (Trew and Everett 2005, Lau and Ip 2006).

The distribution of forces at the fingers and the pinch strategies applied by individuals can significantly vary with different object sizes, although the mechanisms that explain these changes may be different from that of the ones for grip forces (Gurram *et al.* 1995, Aldien *et al.* 2005). Nevertheless, it is crucial to carefully consider the object size in design, and ensure that it is appropriate given the force, precision requirements and the type of pinch grip that will be used for the pinching operation (Persad and Waller 2011).

5.5. *Size considerations in repetitive pinching*

If normal repetitive pinching activities can already cause individuals to sustain hand-related CTDs (Armstrong and Chaffin 1979, Fang *et al.* 1995, Ingram-Rice 1997, Babski-Reeves and Crumtpon-Young 2002, Hayashi *et al.* 2005), the likelihood of sustaining these disorders may be higher with the increase of the pinched object's size. This is because the size of an object affects the maximum acceptable load, energy expenditure and musculoskeletal stress when repetitively pinched (Ayoub and Mital 1989, Ciriello 2003, 2007, Jung and Jung 2010), leading to higher chances of developing hand-related CTDs (Sokas *et al*. 1989, Ellis *et al*. 2004).

Tools that are substantially large can increase the stress of a worker (Jung and Jung 2010) and cause tendon injuries through accidents (Belcher 2012) if the pinching tasks require repetitive movements (Babski-Reeves and Crumtpon-Young 2002, Arvidsson *et al*. 2003). It is therefore essential for precision tools to be designed with an optimum size in order to cater for a possible necessity for a worker to perform repetitive pinching tasks.

6. Conclusions

It may be undeniable that the causal factors of hand-related disorders are yet enigmatic aspects in ergonomics. However, by building on mechanistic insights emerging from previous and recent research, this article has offered a review of shape and size considerations in pinch grips. The literature summary unlocks possible doors for future theoretical and practical explorations.

6.1. *Theoretical implications*

By understanding shape and size considerations in pinch grips, this review provides valuable insights into the scope of interest that both researchers and designers address. The theme addressed in this review also adds to our knowledge on understanding pinch grip mechanisms by optimising the object's shape and size.

This review allows researchers to create causal relationships among shape, size and pinch grips using quantitative and experimental investigation methods. Through these investigations, researchers can enhance predictions on functional outcomes in industrial precision tasks. Also, by combining this review with contact algorithms from other pinch frameworks, the pinch safety margin can be optimised to be more accurate and realistic.

This review is also useful as a basis for researchers to simulate musculoskeletal loadings in fingers for occupational activities involving different tool shapes and sizes. The potential research outcome can involve the production of optimised tool designs.

6.2. *Practical implications*

This review is also beneficial to designers, ergonomists and engineers in general. For instance, design guidelines can be created to enhance the design of precision hand tools for increased performance and reduced injury risks. These guidelines may include special emphasis on shape and size requirements to satisfy the user's preference while obtaining the required amount of phalange forces in a pinching activity.

The literature summary also acts as a useful reference for precision activities involving irregular-shaped/sized hand-held tools. This reference can generally guide engineers and operators on the ergonomics of new tool designs that may cause pressure-induced discomfort if not properly assessed.

The theoretical connections in the literature summary can also be used to help engineers identify the factors that influence an individual's pinch grip strategy. If the correct pinch grip strategy can be known and applied for the corresponding object shape and size, the risks of hand-related CTDs among employees may be significantly reduced.

7. Directions for future research

This review can still use a considerable amount of improvement. It needs sufficient hypotheses, experimental and empirical testing in order to establish an appropriate framework. Employing quantitative research methods may be fitting to explore the conceptual combinations developed in this review.

Defining pinch grip requirements can be considered as a step to understand the relationship between these requirements and the ability of workers in their precision tasks. Research regarding the ability of workers to meet these requirements can include variables such as pinch techniques, postures assumed by workers, obstructions that modify optimal work posture, pinch surface friction and worker ability. Additional research needs to be done to better understand worker abilities and the demands of pinch grip requirements.

By incorporating force sensors on the fingers, pinch force can be measured. This enables researchers to evaluate any type of tool handle or object, of any shape, size or material. Determining the causal relationships among these factors can lead to the development of new pinch grip safety margins for a larger range of object shapes and sizes.

This research can also be improved by possibly including other factors that are not related to the object but more to the pinch grips themselves such as the material and the texture of the pinch grips. By doing this, more possible outcomes can be obtained in the interactions among shape, size and pinch grip. For example, a perfectly round object would ordinarily be considered 'easy' to grasp and pinch. However, if a similar-shaped object with a smooth texture were to be considered, the outcome may be different.

Future studies may also consider the weight range of the pinched object as this factor may have an impact on pinch grip forces. Also, it may be important for researchers to consider the frequency of pinch grips and the ability of maintaining the pinch grip forces with time due to fatigue, for example.

The inability to design precision tools and products that fit the human hand can cause the prevalence of many hand-related CTDs and injuries. Although much remains to be learned about the developed literature summary in this article, it is believed that an extant understanding of shape and size considerations in pinch grips is now within sight, due in part of an improved understanding of how both shape and size can experimentally affect the pinch grip of an individual.

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Relevance for ergonomics theory

This review is useful as a precursory design guideline to enhance the design of precision tools for increased performance and reduced injuries. Further research on this review can enhance the efficacy of precision tasks and other tasks that require the application of pinch grips.