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The Influence of Hand Tool Design on Hand Grip Strength: A Review

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Abstract: Hand is made up of bones, tendons, ligaments, nerves and blood vessels that can be easily debilitated and injured if the hand tool is not design ergonomically. Recently researchers have examined the effects of individual, environmental and occupational factors on hand grip strength. However, information on the influence of hand tool design on hand grip strength is still lacking. The aim of this paper is to provide a comprehensive review of factors influencing hand grip strength focusing more towards hand tool design factors. The authors searched the journal articles, book and guidelines from the online databases of Google Scholar, ScienceDirect and Pubmed. Fourteen factors includes handle diameter, handle length, handle orientation, handle shape, handle material, handle flange, handle inter distance/grip span, grip method, tool weight, tool center of gravity, tool sharpness, trigger type and size, spring stiffness as well as vibration exposure were found to have significant effect on the hand grip strength. This review identified that the handle diameter is the most significant factor for hand grip strength.

Keywords: Ergonomic design, occupational health, gripping task, grip strength model, hand injury, anthropometry

1. Introduction

Hand is one of the vital body parts as it serves multiple functions in our daily life such as holding and gripping objects include handrail, telephone, steering wheel, and hand tools. To do these activities, the hand requires strength. Strength can be defined as the capacity of body parts to produce force or torque with voluntary muscle contraction [1], [2], [3]. Grip strength is a magnitude of muscle strength generated by the hand and forearm muscles while gripping an object. Hand dynamometer and force gauge are the most common devices used to measure the hand grip strength. In industrial ergonomics, information on physical strength is useful for three purposes: 1) hand tool design – as guidelines and references for creating consumer products and industrial hand tools [3], [4]. 2) Worker selection and placement programs - to ensure the jobs involving heavy physical demands are not performed by those who lack the necessary strength capabilities [5]. 3) Job design – to match the worker strength and the job demands [6]. In addition to that, data on hand grip strength are also meaningful for predicting muscle weakness [7], determining the functional capabilities of

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the hand, evaluating the effectiveness of a given hand treatment and assessing the ability of injured worker to return to his/her work [4]. Many researchers from different countries have paid effort to measure the normative value of hand grip strength for the abovementioned purposes. Examples of normative value of hand grip strength which represents countries or population include United Kingdom [8], Greek [9], Malaysia [10], India [11], Saudi Arabia [12], Singapore [13], Turkey [14], Caucasian [15] and American [16], [17]. As summarized in Table 1, factors influencing hand grip strength can be categorized into five domains: individual, environmental, occupational, training and hand tool design.

Table 1- Factors influencing hand grip strength

Domain	Detail factors
Individual	Age, sex, handedness [18]; body position [19]; height and weight, wrist and forearm position [20], [21]; palm length [22]; menopause [23]; menstrual cycle [24]; fitness level [25]; health status [26]; cholesterol level [27]; fatigue [28]; diet [29]; smoking [30], [31], [32]; sleep quality [33] and circadian rhythm [34].
Environmental	Time of day, altitude, oxygen level and temperature [35].
Occupational	Job types [36], glove wore [37].
Training	Unilateral training [38], [39].
Hand tool design	Handle diameter, handle length, handle orientation/ angulation, handle shape, handle material, handle flange, handle inter distance/grip span, grip method, tool weight, tool center of gravity, tool sharpness, trigger type and size, spring stiffness and vibration exposure.
	Note: A thorough review on these factors will be provided in this paper.

A hand tool is an assistive device that is operated by hand. The main function served by most hand tools is to transfer forces generated by the hand onto an object or workpiece. Usually industrial hand tools are developed for specific applications such as torqueing, drilling, grinding and riveting. When dealing with a hand tool, muscles in the hand and forearm generate force while gripping. When a worker gripping a hand tool, the muscles of the flexor mechanism in the hand and forearm create grip strength while the extensors of the forearm stabilize the wrist [40].

In the history of industrial development, poor hand tool design has been thought of as a key factor in occupational health issues. Workers from manufacturing industry and agriculture sector are potentially exposed to high percentage of injuries due to poor design of hand tools [41], [42]. Previous studies pointed that poor design and excessive use of hand tools increase the severity and frequency of acute/chronic injuries of the hand, wrist, and forearm [42], [43], [44]. Fig. 1 illustrates the correlation of hand grip strength and problematic hand tool design, as a function of time. In general, the problematic design of the hand tool has a negative correlation with time of grip strength decrement. High degree of problematic design makes the user utilized the hand tool in awkward posture and contact stress especially in the palm and wrist. This condition will accelerate the chance for muscle strain and poor blood circulation, thus lead to quicker muscle fatigue. Faster muscle fatigue, faster decrement of the grip strength.

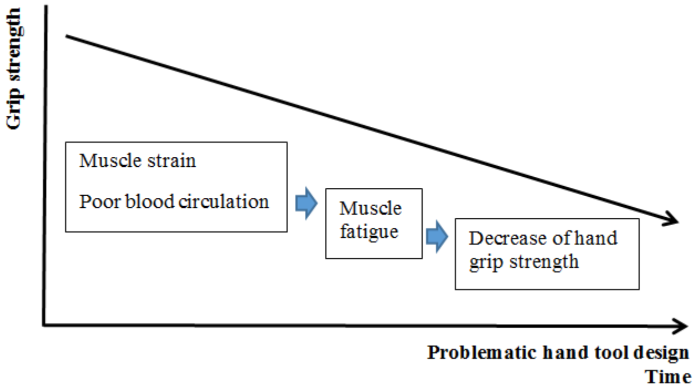

Fig. 1 - Correlation of problematic hand tool design and grip strength as a function of time

Several hand tools have been studied to investigate their effects on the hand grip strength. Examples includes screw drivers [45]; hand wheels [46]; staple gun [47]; powered hand drill [48]; pliers [49], [50]; carpet weaving tools [51]; pruning shears [52] and files [53]. Even though studies on ergonomically design hand tools have gained superior attention from the researchers around the world, the information on the detail factors of hand tool design which affecting the hand grip strength requires further compilation work as they are now available in scattered publications i.e. journal articles [41], [54]; guidelines [55], book [56] and checklist [57]. Furthermore, previous publications in [58], [59] have reviewed the effects of several factors under the individual, environmental and occupational domains on hand grip strength. However, review on the influence of hand tools design on the hand grip strength is still lacking. Due to absent of these collective and comprehensive information, researchers, hand tool designers and manufacturers might not be able to design and manufacture effective hand tools for users in industries.

Therefore, the objectives of this paper were to create a model that presents the domains and detail factors influencing hand grip strength, review the detail factors under the domain of hand tool designs and propose suggestions for future research.

2. Methodology

The authors searched the data sources such as journal articles, book and guidelines from the online databases Google Scholar, ScienceDirect and Pubmed. The keywords typed were hand grip strength; hand tool and hand grip strength; handle diameter; handle length; handle orientation; handle shape; handle material; handle flange; handle inter distance/grip span; grip method; tool weight; tool center of gravity; tool sharpness; trigger type and size; spring stiffness and vibration exposure. Then the full texts of journal articles were downloaded. Articles were included in the review if they meet these criteria: describing relationship between hand tools design and hand grip strength, and were written in English. The references list of these articles was checked for additional relevant articles. More than 200 articles were collected by the searches. The titles and abstracts of these articles were screened. Out of which, 151 journal articles (published from 1962 to 2017), 6 books, 4 guidelines and 2 conference proceedings were included in the final review. The review was started by identifying domains that influencing the hand grip strength. Five domains identified: environmental, occupational, training, individual and hand tool design. The detail factors under each domain were further investigated. Fourteen detail factors under the hand tool design domain were then reviewed thoroughly. Finally, the authors visited a machine shop to capture relevant photo of hand tools to assists the explanation of the detail factors.

3. Results

Fig. 2 illustrates a model which represents the domains and detail factors influencing hand grip strength. Environmental, occupational and individual domains were reviewed by previous studies [58], [59]. Hence the detail factors under the domain of hand tool design are further discussed in this section.

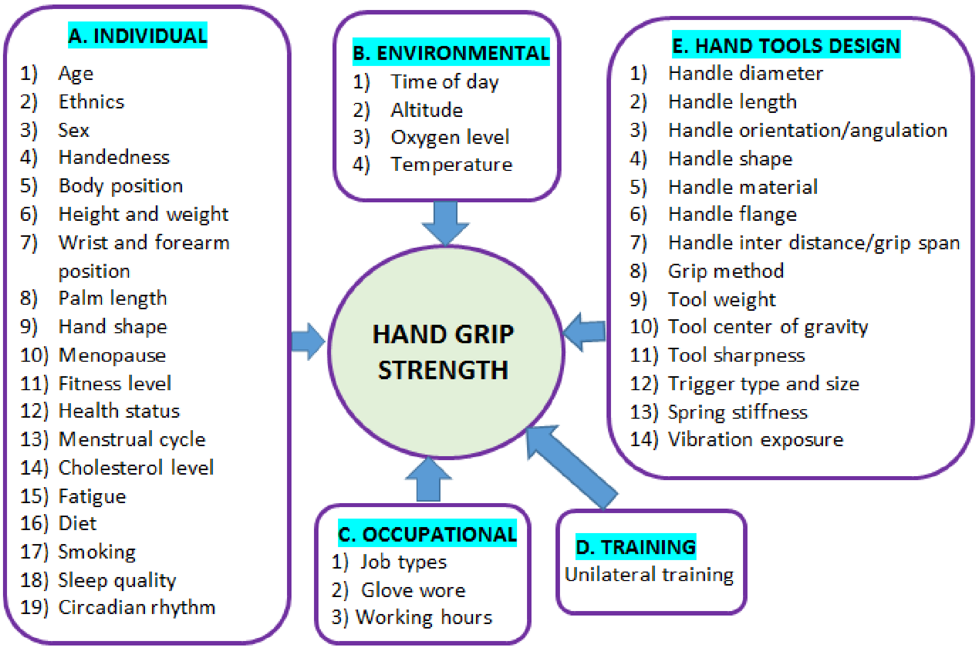

Fig. 2- Domain and detail factors influencing hand grip strength

3.1 Handle Diameter

Handle is one of the important components in the hand tool fabrication. Regardless power or non-powered hand tools, the handle acts as an interface between the user's hand and the hand tool. An ergonomic design of hand tool's handle may contribute to high work productivity, comfort and better grip performance. A reputable study [60] confirmed that the handle diameter and hand length are the contributors to high grip strength. Two studies identified that the hand grip strength decreases as the handle diameter increases [61], [62]. Edgren and colleague [63] studied the effect of power grip in different instrumented cylinder ranging from 25.4 to 76.2 mm diameter. It was found that the average magnitude of hand grip strength increased 34.8 N as handle diameter increased from 25.4 to 38.1 mm and then monotonically declined 103.8 N as the handle diameter increased to 76.2 mm. Recommended handle diameter varies. Based on the study conducted by Saran [64], a 25 mm handle diameter is preferable than 19 mm or 32 mm. However, Drury [65] recommended handles with a range of 25 – 40 mm rather than decide a single optimum size. Ayoub & Presti [66] found that a 38 mm diameter of handle is optimum size based on the ratio between force and the electromyography activity. Different population with different muscle strength and palm size determines the handle size. To solve this issue, it is suggested to design different size of handle, to satisfy the population of males and females. Table 2 summarizes the studies related to handle size of hand tools.

Table 2 - Studies related to handle size

Studies	Handle diameter studied	Key findings
[67]	32 mm	This diameter required least effort as quantified by electromyography in the forearm.
[68]	25 - 50 mm	The maximum torque was the largest with the 45 and 50 mm diameter handles and least with the 25 mm diameter handle.
		35 - 45 mm handles were rated as the most comfortable for maximum torque exertions.
[62]	30, 35 and 40 mm	Most comfortable for maximum grip force exertions.
[69]	33 mm	Optimum diameter tool handle for males and females.
[70]	30 mm	The maximum grip force is 1.42 greater than the minimum grip force.
[71]	18 – 39 mm	The highest hand grip strength is found in handle diameter of 18 – 37 mm, the lowest is 22 – 39 mm.
[72]	30 - 50 mm	30 mm diameter handle contributed highest wrist torque strength.
		30 mm and 40 mm diameter handles caused less discomfort and better usability.
[63]	25.4, 38.1, 50.8, 63.5, and 76.2 cm	Grip force increased by 34.8 N when handle diameter increased from 25.4 cm to 38.1 mm. It consistently declined by 103.8 N as the handle diameter increased to 76.2 mm.
[73]	(1) A handle diameter matched to the user's inside grip diameter;	Handles 1.0 cm smaller than the user's inside grip diameter may reduce effort and the potential for injury.
	(2) A handle diameter 1.0 cm smaller	
	than the user's inside grip diameter; and	
	(3) A handle diameter 1.0 cm larger than the user's inside grip diameter.	
[74]	22 and 35 mm	Handle diameter is significantly influenced the temporary threshold shifts in fingertip vibrotactile perception at 125 Hz–5.0 m/s^2 rms vibration.
[75]	30, 40 and 50 mm	Increasing the handle size yielded higher 'driving-point mechanical impedance magnitude' of vibrating tool handle.
[76]	Multiple sizes of handle diameter	Increasing the number of handle sizes improves levels of population accommodation.
[77]	35 – 40 mm	As the handle perimeter decreased the handle becomes less preferred.
[78]	30, 40, and 50 mm	Cylindrical handles with a diameter between 30 and 40 mm allow for the greatest grip force production.
[79]	25, 27.5, 30, 32.5, 35, 37.5, 40, 42.5 mm	The optimal diameter is depending on hand sizes.
[80]	121 to 127 mm (handle circumference)	Symmetrical, pistol-shaped knife handles with circumferences of 121 to 127 mm are the least fatiguing and most preferred.
[81]	29, 38, 45, 51, 57 and 64 mm	Muscle activity in the forearm flexors is minimum with use of handle diameters 51 mm or bigger.
[82]	34.3 and 40.9 mm	Interactions between handle diameter and grip strength during extension, flexion, ulnar deviation, and radial deviation are not significant.
[83]	38, 67, and 84 mm	25% increase of torque with the medium diameter handle compared to the small one

3.2 Handle Length

Referring to the basic mechanics, a hand tool with a longer handle allows the user to generate more moment by applying a small amount of force at a greater distance thereby minimizing the required muscle effort. Too short handle is not enough to reach the breadth of the palm and can cause compression on the tissues and nerves. The length of the handle should be extended beyond the hand to produce high moment for better task performance (Fig. 3a). In addition, designing the tool handle using the ergonomics principles can gain a good acceptance rate from the users [51]. Table 3 tabulates the handle length studied by previous works.

Table 3 – Handle length studies

Studies	Handle length studied	Key findings
[84]	200, 250, 300 and 350 mm	The optimal spatula handle lengths for frying food, turning food, and shoveling food are 200, 250 and 250 mm respectively.
[83]	38, 76, and 127 mm	15% increase of torque with the long handle compared to the short one
[85]	80 mm and 125 mm	A bar clamp handle with 125 mm length could clamp an object more tightly and had better efficiency with less forearm fatigue.
[86]	45 mm, 48 mm, 49 mm, 141 mm and 145 mm	Long-handled hoe appears to have the potential to improve worker productivity, comfort, and safety.
[87]	180, 210, 240, 270, 300 and 330 mm	The chopsticks about 240 mm long were the optimal for adults, and those about 180 mm long were the optimal for children. The shorter the chopsticks, the stronger the pulling force.

3.3 Handle Orientation/ Angulation

Handle orientation (Fig. 3b) is the angular position measured from the horizontal plane to the handle axis. Good angulation of the handle is required in hand tools design to maintain the wrist in neutral posture. In general, handle orientation in the range of 70° to 80° is recommended [88]. Improper handle orientation leads to awkward posture in the wrist/ hand and consequently reduces the grip strength. It is also has a potential to cause compression of nerves and blood vessels in the hand. Recent study pointed that the handle orientation influences the grip strength of hand while grasping the tool [89]. Table 4 shows the key findings on the handle orientation studies.

Table 4 - Studies on handle orientation

Studies	Handle orientation/ angulation	Key findings
[62]	Vertical and horizontal	Hand torque output and flexor muscle activity in the horizontal orientation were higher than the vertical orientation.
[89]	Vertical and horizontal	Grip strength was greatest in horizontal orientation.
[90]	1) Pistol grip tool on vertical and horizontal orientations. 2) Right angle tool on horizontal orientation.	Height and reach distance within a workspace affect power grip force capacity. Grip force increased with height for the right angle tool handle and decreased for the pistol grip tool handle.
[91]	Handle angle (0°, 20° and 40°) and hammering orientation (bench and wall).	Hammer handle angle did not significantly affect forearm muscle fatigue and discomfort rating.
[92]	1) Straight handle 2) right-angled handle	The right-angled handle has not decrease muscle fatigue over the straight handle paint brush.
[53]	1) Straight handle (180°) 2) Angled handle (50°, 60°, 70° and 90°)	The average decrease of grip force in using the angled handled flat files was smaller than the decrease of grip force in using the straight handled.

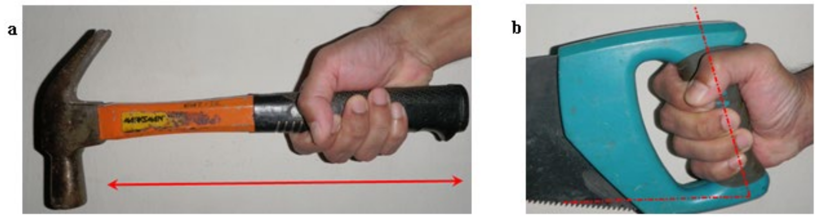

Fig. 3 – (a) handle length; (b) handle orientation

3.4 Handle Shape

The handle shape (Fig. 4) is determined by the technique applied by the user when gripping and pinching the handles [93]. The shape of the handle plays an essential role to allow a maximum usability and work efficiency. Moreover feeling of discomfort can be reduced by designing a suitable shape of handle [94], [95]. According to Dianat [71], the shape of the handle appeared to be the critical factor in capability of contact pressure distribution and affects the subject discomfort ratings. In other words, the load on the tissues can be spread by altering the design of handle shape. Table 5 summarizes the effects of handle shape on hand grip strength.

Fig. 4 – Handle shape

Table 5 – Handle shape studies

Studies	Handle shape studied	Key findings
[96]	1) Longitudinal cross-sectional shapes: circular, hexagonal and triangular. 2) Lateral shapes: cylindrical, double frustum, reversed double frustum and cone.	Circular, cylindrical, and double frustum handles exhibited the least total finger force associated with screw insertion. Circular with double frustum handles were associated with less discomfort and total finger force.
[97]	1) Longitudinal shapes: circular, hexagonal and triangular. 2) Lateral shapes (cylindrical, double frustum, cone and reversed double frustum).	Screwdriver handles designed with combinations of circular or hexagonal cross-sectional shapes with double frustum and cone lateral shapes are optimal in screw-driving torque task.
[98]	1) D shaped 2) A shaped	Greatest grip strength with D shape and the least with A shape.
[71]	Curved, protruding edges, larger diameter at the distal end of the handle, broader at forward end.	Highest grip strength was recorded in the curved handle.
[99]	A shaped.	The highest grip strength was obtained at 45 mm and 50 mm grip spans in grasping A type handle.
[100]	In-line and pistol-grip handle.	The in-line handle configuration is no better than the pistol configuration except when grasping at 90° to the laparoscopic user.
[101]	Round, hexagonal, tapered round and tapered hexagonal.	Handle with a tapered, round shape and a 10 mm diameter required the least muscle load and pinch force when performing simulated periodontal work.
[102]	Circular and elliptic cylinders	Maximum torque was 25% greater for the elliptic than the circular cylinder.

3.5 Handle Material

The materials used to develop the tool handle determine the texture and friction properties of the handle. The handle is suggested to be covered by adhesive tapes and vinyl rubber to reduce manual exertion [103]. Johnson [104] recommended that force exertion can be reduced by adding a brace or vinyl sleeve on the handle. An ergonomically design of hand tool handle is fabricated from non-conductive and non-slippery materials. One of the most commonly used materials is rubber. It offers a super performance in terms of a firm grip, averts the handle from slipping out of the hand and minimizes contact stress in skin and soft tissue of the palm whilst grasping the handle. A study revealed that a plier handle which wrapped with rubber provides lowest hand muscle effort and increase user satisfaction [105]. Combination of rubber and polyurethane foam has been proven to be effective material for tool handle to reduce contact pressure [106]. Handles manufactured of compound rubber or plastics are suggested if the tools are required electrical and heat protection.

Another important design criterion of a hand tool is texture of the handle. Handle texture or roughness of the handle surface determines the friction or slippage between the hand and the handle. A handle covered by a good texture is capable to improve grip surface and increase the friction between the hand and the handle. The texture of the handle is not only invented for gracious appearance but also practicality [107]. A study found that a low-friction handle would result in a 16 – 42 % reduction in grip force compare to high-friction handle [104]. Hence a non-slip texture is suggested for the handle surface [108]. A suffice friction must be applied between the contacting surface of the hand and the handle to ensure a secure grip and to avoid slippage. Handle surface which do not provide a suffice amount of friction requires the hand tool users to exert greater grip force, which can cause greater effort and even loss of tool control. For example, in automotive industry, friction of the tool handle plays a significant role where a considerable force must be applied by a sweaty or oily hand to tighten a small nut in a limited work area. Another advantage of applying adequate friction between the hand and the tool can minimize the force needed to transfer and lift the tool [109], [110]. Table 6 tabulates the findings of previous researches on handle materials.

Table 6 – Findings of previous studies on handle materials

Studies	Key findings
[111]	Handle surface roughness is one of influential factors in relation to the capacity to apply a torque to a knife handle.
[112]	The roughness of the tool handle has a significant effect on the tactile perception.
[113]	A very low correlation between kinetic coefficient of friction and perceived discomfort.
[114]	Larger contact area at the interface of hand and handle produced greater friction.
[115]	Tools with a medium or coarse knurled textured provide the largest coefficient of static friction.

3.6 Handle Inter Distance/ Grip Span

Engineers and tool designers believed that the handles inter distance or grip span (Fig. 5) is one of the essential hand tool design factors. Usually, crushing, gripping or cutting tools such as pliers or tongs are equipped with two handles. An optimum handles inter distance is capable to maximize the hand grip strength and reduce stress exerted on the flexor tendons. Greenberg and Chaffin [116] recommended that the handle inter distance should be in the range of 64 mm and 89 mm in order to achieve high grip forces. Another study found that the maximum grip strength can be obtained at a handle inter distance between 50 mm and 60 mm [117]. Recent studies revealed that handles inter distance of 47.6 to 60 mm provides the maximum hand grip strength [49], [118]. On the other hand, too large or too small handles inter distance will be problematic for some users thus affect their grip strength. For European population, Fransson & Winkle [119] recommended that an optimum handles inter distance is in the range of 55 to 65 mm for males and 50 to 60 mm for females for better grip strength. However, the optimal handles inter distance for maximum hand grip exertion among Asian people might be different due to population differences. Table 7 summarizes previous studies on handle inter distance or grip span.

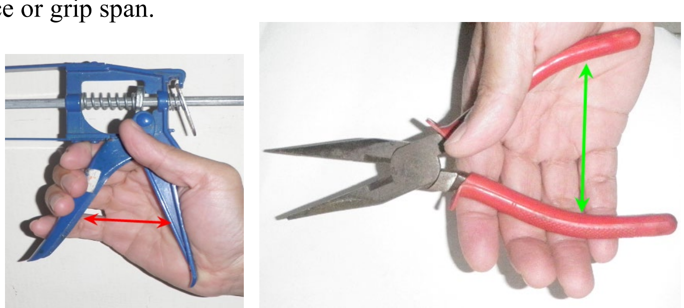

Fig. 5 – Handle inter distance or grip span

Table 7 – Studies on handle inter distance or grip span

Studies	Handle inter distance studied	Key findings
[118]	47.6, 60.3 and 73.0 mm	A grip span of 47.6 mm can exert the maximum hand grip strength.
[120]	63, 80, 90 mm	At 90 mm grip span, the forces required to actuate the handles would be over 90% of the maximum grip strength.
[121]	45, 50, 55, 60, 65 mm	The most comfortable sizes were 50 and 55 mm.
[122]	range of 30 – 105 mm, separated with 0.5 cm intervals	The results indicate that the best biomechanical leverage of fingers for grip force generation is at thumb crotch length at 2 cm requires the least amount of muscular activity, thus, least energy expenditure.
[49]	45 – 80 mm	50 – 60 mm was recommended as the most desirable grip spans of combination pliers. 80 mm grip span showed the least grip strengths and the most discomfort rating.
[99]	45, 50, 55, 60 and 65 mm	The highest grip strength was obtained at 45 mm and 50 mm grip spans. The lowest subjective discomfort was observed in the 50 mm grip span.
[123]	45, 50, 55, 60, 65, and 70 cm	Hand size and optimal grip span correlated in women but not in men.
		In adult men, optimal grip span can be set at a fixed value (5.5 cm)
[124]	45, 50, 55, 60, 65, and 70 cm	The optimal grip span was influenced by hand span in both male and female. Approximately 60 mm for men and 58 mm for women.
[125]	35, 40, 45, 50, 55, 60, and 65 mm.	The optimal grip span ranged from 42 to 52 mm for girls, and 42 to 53 mm for boys aged 6 to 12 years.
[119]	41, 50, 60, 70, 80, 90 and 100 mm	The optimal grip span was suggested to be 50 to 60 mm for women and 55 to 65 mm for men
[126]	50, 60, 70 mm	The maximum grip strength was obtained when the grip span is set to 50 to 60 mm for women and 55 to 65 mm for men.
[60]	34, 47, and 60 mm	Grip strength is significant higher at 47 mm and 60 mm grip span compare to set at 34 mm.
[127]	Grip circumference sizes: (100 mm), 130mm, 160 mm, and 180 mm	The optimal span is closely related to the middle of the length span of the finger flexors
[128]	35, 47, 60 mm	Optimum range of grip span from 47 to 60 mm.
[129]	45, 50, 55, 60, and 65 mm	Small hand size produced the highest grip forces at the 45mm grip span, middle hand size provided the highest grip force at the 55mm, whereas large hand size exerted the highest grip force at the 55mm. followed by 60mm.
[130]	48.7, 52.5, 54.1, 58.3, 59.5mm 64.1 mm	Grip strength decreased significantly at 52.5 mm in men and 48.7 mm in women.

3.7 Grip Method

It was observed that the handles and grips of hand tools are designed for a power grip (with the exclusion of hand tools for precision tasks such as jewelry and microsurgery). An early study stated that ability of hand to produce force is influenced by the grip methods, whereby the maximum force can be obtained when applying traditional grip [119]. Cha and his company [131] revealed that using all 5 fingers gives greatest grip strength, whereby the middle finger is the most significant contributor to grip strength. On the other hand, the weakest grip strength is without the middle, ring and little fingers.

A reputable research found that grip methods contributed a significant physiological effect on flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis, and extensor carpi ulnaris muscles [132]. The study identified that the highest levels of muscle contraction presented in power grip, meanwhile the lowest are chuck pinch and pulp pinch grips. Additionally, muscle activity is greater and endurance lesser in combinations with deviated wrist postures and more powerful grips [132].

3.8 Tool Weight

One of effective solutions to reduce grip force requirements is minimizing the tool weight [73]. A heavy tool causes the hand to exert more forces and thus reduce the grip strength. A continuous gripping or high repetitive of handling of a heavy tool can induce muscle fatigue. The weight of the tool influences the technique used by the user to hold the tool; using one or both hands to stabilize the tool; the maximum duration the user can hold the tool; and the degree of precision which the tool can be manipulated. James [133] suggested that the best weight limit for the tools operated with one hand is 1.4 kg or less and 0.5 kg or less for the tool used in precision tasks. Ideally, the user should be able to operate the hand tool with one hand. The Canadian Center for Occupational Health and Safety found that the tool weight of less than 2.3 kg is recommended when it is away from the body or above shoulder height, and 0.4 kg for precision tools which allow a good control [134]. These numbers show a suitable weight of a hand tool; however, the interaction between the tool weight and the hand grip strength remain unexplored.

3.9 Handle Flange

Some hand tools' handle such as screwdrivers are equipped with a flange to increase its usability (Fig. 6). However, adding a flange to the handle does not significantly influence the grip strength [73]. The sharp edges and contours on the handle should be covered with cushioned tape or rubberized materials to minimize contact stress which can affects grip strength.

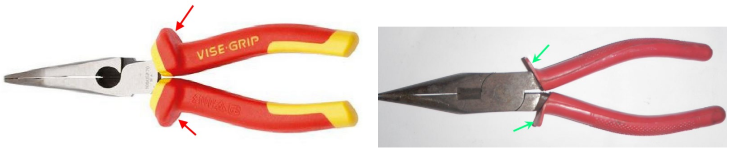

Fig. 6 – Handle flange

3.10 Tool Center of Gravity

The basic mechanics applied in the hand tool design is its center of gravity (Fig. 7). The tool designer is suggested to align as close as possible the center of gravity of the hand tool with the center of the hand which gripping the tool [116], [135], [136]. This principle allows the wrist to free from the moment (rotational force) caused by the tool weight. On the other hand, a large distance between the tool center of gravity and the hand center may put stress on the wrist and reduce the grip strength. For example, a nut runner which is heavy at its front side will require extra effort from the hand, wrist and forearm to hold during the nut torqueing.

Fig. 7 – Center of gravity of tool and hand

3.11 Tool Sharpness

A laboratory study remarked that the tool's blade sharpness clearly had a significant influence on the grip forces for meat cutting operations. Knives with sharper blades requiring lower grip effort than dull knives [137]. In metal fabrication industry, hand tools such as a chisel requires a sharp cutting point to reduce the muscle effort in gripping the chisel to cut the workpiece. Otherwise, overuse of muscle due to a dull cutting point can reduce the grip strength.

3.12 Trigger Size and Type

While operating the trigger of powered hand tools such as a nut runner, the index finger is exposed to repetitive movements. This practice can lead to a considerable risk for tendonitis in the index finger. If a powered hand tool is equipped with a longer trigger, it allows the use of two or three fingers to activate the trigger, thus minimize the tendonitis risk and discomfort. Trigger type had a significant effect on finger and palmar forces. Average forces were consistently greater for the conventional trigger than for the extended trigger. Hence, the extended trigger may be beneficial in terms of reducing hand force and exertion levels during tool operation [138]. Fig. 8(a) illustrates trigger of a hand drill.

3.13 Spring Effects/ Stiffness

Some two-handle hand tools such as pruning shears and pliers use a coil spring between the handles, as shown in Fig. 8(b). A spring has mechanical properties called as stiffness (measured in N.m). In hand tool design, spring stiffness refers to ability of the handles to return to their original position in response to the grip force. Generally, the force needed to use a handle should be less than one-third of average possible maximum for the user population [57]. A previous study highlighted the use of spring displayed a tradeoff effect on handle operation [105]. The negative effect of spring might be due to an additional effort required against the spring force. Meanwhile the positive effect could be due to assistance of grasping and releasing of the handles. Selection of spring stiffness is crucial in the hand tool design, however, very minimal studies been conducted to determine the effects of spring stiffness on the grip strength.

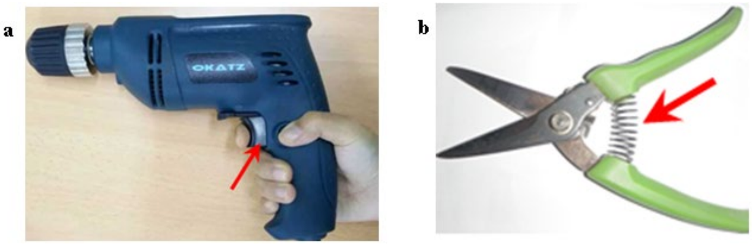

Fig. 8 – Hand drill trigger

3.14 Vibration Exposure

Powered hand tools such as nut runner, hand drill and rock breakers use electric motors and 2-stroke engine (e.g. chain saw and earth auger) to operate. These motors and engine will certainly produce mechanical vibration. Workers who utilize a continuous forceful gripping to the handles of these vibratory powered hand tools can be at risk of experiencing musculoskeletal disorders [139], vascular disorder and sensori-neural disorder [140] and hand–arm vibration syndrome or white finger phenomenon. Long term exposure to hand–arm vibration has been shown to result in occupational health issues such as numbness and decreased grip strength [141], [142]. A continuous usage of vibratory powered hand tools can lead to excessive grip force, which may elevate the chance for muscle fatigue and grip strength decrement, as reported by Widia and Dawal [143]. Average grip force increased by 27% (from 25.3 N without vibration to 32.1 N for vibration) at vibration frequency of 40 Hz [144]. Widia and Dawal [141] measured grip strength before and after using electric and bench drills to drill through wood for 5 minutes and 15 minutes. Results of their study showed that greater decrement in grip strength associated with higher vibration magnitude and longer exposure durations. An onsite assessment found that the percentage of decrement of hand grip strength after operating a vibrating grass cutter is in the range of 5% [140]. Studies on vibratory hand tools pointed that grip force errors were highest when vibration exposures in the frequency range from 31.5 to 63 Hz [145], [146].

4. Discussion

Designing an ergonomic hand tool requires considerations from various aspects such as individual, environmental and occupational factors. Based on the results of review, the authors concluded that there are 14 factors of hand tools design influencing the hand grip strength: handle diameter, handle length, handle orientation/ angulation, handle shape, handle material, handle flange, handle inter distance/grip span, grip method, tool weight, tool center of gravity, tool sharpness, trigger type and size, spring stiffness and vibration exposure. Among them, the handle diameter shows the most significant factors and many studies been performed to find the optimum size of handle size. Handle is one of the important parts of hand tools as it functioned as an interface between user and the tool. Problematic handle design causes usability, discomfort and work efficiency issues. Hand tool handles available in the market have variations in terms of diameter, length, shape and materials. For example, the diameter of hand grinder handle is larger than the hammer handle. The hand grinder's handle is too big for a female user (Fig. 9a) and may cause insecure grip and discomfort in grinding process. Additionally, the support handle for hand (Fig.9b) is suitable for grinding in horizontal surface, however, for vertical and overhead tasks the support handle does not work. The support handle cannot be used efficiently in grinding a slot on the wall (Fig. 9c). This condition can lead to discomfort in the upper extremities and slow down the work productivity.

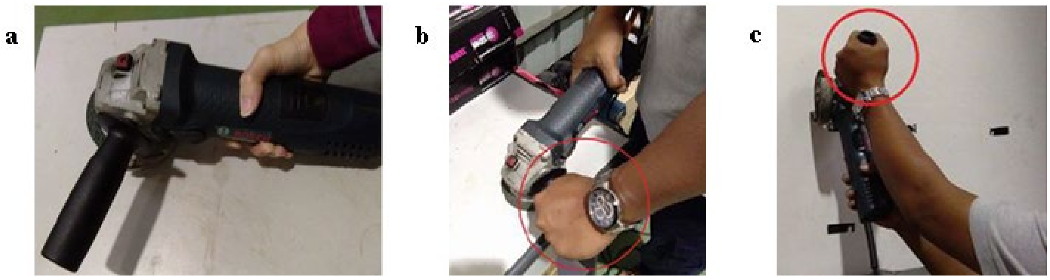

Fig. 9 – (a) Handle is too big for female; (b) support handle for hand; (c) impractical to grind slot on wall

As part of bigger study, it was found that there were also other factors that may influence hand grip strength. Many studies documented the individual factor as one of the main contributors affecting grip strength. These include hand sizes, hand dexterity, handedness, gender, age, ethnicities, psychological condition, and others. To grip the handle, our hand requires strength. Hand grip strength is affected by the individual factors or human variability such as anthropometry. Anthropometry and body size are depending on age, gender, racial and ethnic group, countries, occupational, generational or secular, and transient diurnal [147]. Body size has relationship with muscle strength and movement performance [148]. Muscle size and grip strength are associated with bone size and strength [149]. Human strength is not dependent on physical factor alone, but psychological as well. Depressed mood is also can be associated with the increased risk of steep strength decline [150], [151], [152]. Gender factors such as menopause is also can be linked to decline in grip and pinch strength [153]. Due to the fact of anthropometry and human strength vary among populations from different countries, hand tools developed based on American or European might not be suitable for Asian industrial workers. However, multi-size snap-on-handles and adjustability feature can be considered as solutions to this compatibility issue. Another concern is handedness. It was found that the dominant hand is approximately 10 % stronger than the non-dominant hand [154]. Many hand tools are designed for right-handed user to accommodate majority of the world's population. It was observed that majority right-handed tools may be inconvenient or not user friendly for left-handed users. Hence more left-handed tools such as circular saw, can openers and peeler are needed to cater the lefties.

Based on above review, almost experimental studies performed by the previous researches invited healthy participants to acquire the normative hand grip strength datasets. Usually, product designers or ergonomists refer and apply these datasets to design the hand tools. These datasets may not represent the actual working population in the industries which consists of different level of health status such as having symptom of carpal tunnel syndrome and non-occupational diseases. Previous studies proved that rheumatoid arthritis, osteoporosis, carpal tunnel syndrome and hand hemodialysis [155], [156], [157], [158], [159]; hypertension, diabetes, high cholesterol and heart disease weaken the hand grip strength [160], [161], [162]. Hence two questions may appear: 1) Are the existing procedures on measuring the hand grip strength required additional protocols (for e.g. checking the blood pressure and sugar level) before inviting the subjects? 2) Are the existing hand tools can fit to workers who having work-related musculoskeletal disorders and non-occupational diseases? This can be solved by applying advanced technology such as microcontroller, for example, design and development of hand gripper to help workers who are having hand injury due to accident and diseases [163].

5. Conclusion

In conclusion, there are multiple factors contributing to hand grip strength. As such, the design of task and activities that require grip strength need a comprehensive consideration on the contributing factors that may affect grip ability. There were 14 handle tool design factors which were studied by previous researchers was reviewed and compiled in this paper. They include handle diameter, handle length, handle orientation, handle shape, handle material, handle flange, handle inter distance/grip span, grip method, tool weight, tool center of gravity, tool sharpness, trigger type and size, spring stiffness and vibration exposure. Based on this review, the authors concluded that the handle diameter is the most significant factor. Understanding of these contributing factors would allow engineers and designers to determine ways to fit the hand tools to workers.

This manuscript has been primarily focused on hand tool design factors to influence hand grip strength. Further study on this topic area may focus on compilation on other occupational factors such as task exposure and frequency of hand tool usage to get a more comprehensive overview of work-related factors that can contribute to hand grip strength. In addition, non-work related factors (i.e. aging population or senior citizen workers) to influence hand grip strength can also be further explored, especially in relation to how it might impact work performances, as well as safety and health risks. Comprehensive review on both work-related and non-work related factors to influence hand grip strength will provide a better understanding, especially to engineers and designers in their effort to find good configuration and balance between work systems and workers.

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