Hand Parameters and Walking Stick Design: A Case Study among Elderly Malaysians

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Abstract—**According to the World Bank, in 2015, the elderly population reaches 8.5% of the world's population. This number grows at 0.13% per annum. In Malaysia, the growth reaches 0.2% of this population annually. Assistive tools such as a walking stick to support the elderly people have become necessary. However, much uncertainty still exists about the relation between the walking stick design and the Malaysian elderly. The objectives of the study were to measure hand dimension and hand grip strength of Malaysian elderly and to relate the hand dimension with the walking sticks being used. There were 50 Malaysian elderly participated in this study and three designs of walking stick available in the market were tested. The first design (handle A) was round and padded, the second design (handle B) was rectangular curve and the third design (Handle C) was round curve. Statistical analysis between hand size and hand surface area shows a linear relationship with R^2 = 54% and significant with p-value < 0.05. As for the relationship between the contact area of stick handle and hand size, a linear relationship was found with R^2 = 53.3% for handle A, R^2 = 46.5% for handle B, and R^2 = 36.6% for handle C. This study concluded that the walking stick with high contact area provides better grip and comfort.**

Keywords—hand contact area; hand size; inside grip diameter; hand grip strength

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I. INTRODUCTION

The United Nations Population Funds describes that elderly is referred to citizens with the age of 60 years and above [1]. Recent literature highlighted that there is no exact definition of the word 'elderly' as this term is perceived contrarily in different cultures and generations [2]. Worldwide statistics indicate that the elderly population has been progressively increasing in most economically developed countries such as the United States and Australia [3].

Currently, in Malaysia, the number of the total population is estimated at 32 million. Out of the total population, children make up less than one-fourth of the total population (24.1%) and citizen with aged 65 years and above comprise 6.2%. Malaysia will have a nearly equal share of the young (18.6%) and older population (14.5%) in 2040. By this time, there will be three elderly citizens for every 20 population [4]. To date, the percentage of the elderly population (aged 65 years and above) is increasing 0.2% compared to 2016 [5]. This statistics shows that Malaysia is experiencing an ageing population, as faced by many high and middle-income countries [6].

As the elderly citizen population grows, they will require more care and attention. However, in Malaysia, there are many elderly people who live alone when their children go out for work [7]. According to research conducted in Malaysia, out of 4842 respondents aged more than 60 years old, 205 (4.23%) of them had experienced home injury associated with falls [8]. To date, a cross-sectional study revealed that one in every 25 Malaysian elderly living in a community setting experienced falls in 2015 [6].

The above mentioned statistics illustrates a preliminary picture of the demand for the usage of walking aids among elderly people in Malaysia. A walking stick is commonly used by an elder citizen as a mobility aid as well as a preventative measure to avoid falls. The walking stick is useful to improve body balancing, stability and even can reduce pressure in the joints that might be causing pain. A reputable research pointed out that the elderly use a walking stick to prevent falls caused by balance and postural disorders [9]. It is observed that an elderly is typically prefer a walking stick as walking aid, inexpensive, easy to use and accessible in the market.

Due to the ageing process, among the elderly problem mostly found is the capability to walk decline because of loss of some the muscle fibres that make up the muscles which then affects the muscular movements and body balance [10]. It makes the elderly people requires greater muscular strength compared to other age groups so that they can easily move and perform daily routine without difficulties. Again, the demand for walking aids such as walking stick will increase in the near future. This issue raised the importance of knowledge on parameters of elderly people's hand. Principles of ergonomics design in assistive tools need to be applied. Hand parameters such as contact area, hand area, inside grip diameter and grip strength need to be considered in the design of assistive tools.

To the best of authors' knowledge, the study on hand parameters and the design of walking stick handle, particularly in grip strength and grip contact area among Malaysian elderly is still minimal. Hence, the aim of this study was to investigate the hand parameters (hand width, hand length, hand size, contact area and inside grip diameter) and hand biomechanics (grip strength) among Malaysian elderly in accordance with the suitability of walking sticks available in the market.

II. METHODOLOGY

A. Subjects

This study involved 50 elderly Malaysians from an old-folks home situated in Melaka. The subjects were selected based on their willingness to participate, and the number represents more than 90% of total occupant in the old-folks home. The age ranged from 61 to 90 years old and the mean age was 71.5 years old. The subjects represent the three main ethnic groups in Malaysia (Malay, Indian and Chinese) and they were using a walking stick in their daily lives. In the study, subjects used their dominant hand, either right hand or left hand. Subjects came from various past occupation background. No selection criteria had been imposed for health status but they were free from serious injuries and surgery. Subjects were given informed consent and given a brief explanation before the data were collected.

B. Hand length, hand width and inside grip diameter measurement

Fig. 1 shows the measurement references for hand length and hand width. Letter (a) represents the hand length, and letter (b) shows the palm breadth. The hand length is measured from the wrist crease to the tip of the middle finger by using measuring tape [11], [12], [13]. The palm breadth was measured by using digital calliper (Mitutoyo, Japan) from second to fifth metacarpal [12], [13].

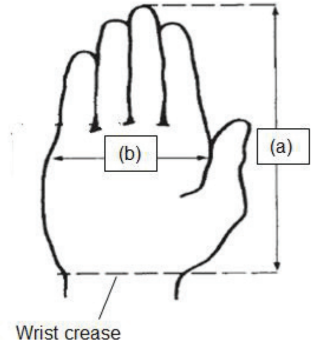

Fig. 1. Hand length (a), hand width (b) [14]

Method to measure the inside grip diameter was referred from previous studies [15], [16]. The method uses a conical tool. In measuring the inside grip diameter, the conical tool was held in such a way that the middle fingertip was touching with the thumb tip. Results of the hand anthropometry measurement were rounded to the nearest centimetre.

C. Grip strength measurement

Jamar hand dynamometer was used to measure the grip force exerted by the subjects (Fig. 2). This device has been recognized to give the most accurate measure of grip strength. The procedures were: (1) Subjects in seated posture and relax condition; (2) Dominant hand and the elbow are flexed at 90° and the arm and wrist in a neutral position; (3) The subjects squeeze the dynamometer handle at their maximum effort; (4) The grip exertions were held for 5 seconds; (5) The procedure was repeated for three trials. The average of grip force from three trials was considered in the further statistical analysis. These procedures have been applied by recent studies [17], [18], [19].

The subjects were given one minute rest period between each squeeze. The second handle position of the Jamar hand dynamometer was used as the grip span setting in the measurement.

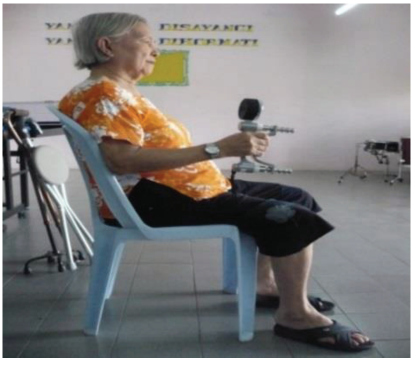

Fig. 2. Subject performing hand grip strength

D. Contact area and hand surface area measurement

This study was also measured the contact area and hand surface area which contacts the palmar side and the handle surface. The measured contact area helps to determine pressure concentration on the handle. Three types handle of the walking stick were used in this task; round and padded or Swan-neck (Handle A), rectangular curve or T-handle (Handle B) and round curve or Crook handle (Handle C). The dimensions are; Handle A (length =13.6cm, diameter = 3.4cm); Handle B (length = 14cm, major diameter = 3.8cm, minor diameter = 2.6cm); Handle C (length = 13cm, diameter = 3.2cm). As shown in Fig. 3, these three walking sticks are the most preferred by the elderly people in Malaysia.

Fig. 3. Handle A (left), handle B (middle) and handle C (right)

Data on hand surface area were determined by referring to the palmar side surface area in flat lay position (without grasping any objects). Then, the data will be compared to hand size. The purpose of comparison was to find out whether the hand size influences the hand surface area. Early assumption suggested that people with large hand size will also have a large hand surface area or vice versa. Having a large hand surface area means the person produced a large contact area on the gripped handle, plus the grip forces were evenly distributed.

The measurement procedures for hand surface area and contact were referred to an established study, whereby the subjects' palm was painted with a thin layer of ink [20]. In order to obtain the hand surface area, subjects required to place the inked palmar side on the sensitive paper. While for contact area, a sensitive paper was wrapped on the handle of walking stick which later the subjects were asked to grip the handle with their inked palm. The total hand surface area and contact area were estimated by summing the inked area of the sensitive paper on the graph paper and multiplied with 0.04 cm^2. (Note: 0.04cm^2 was the size of small grid column on the graph paper).

III. RESULTS AND DISCUSSION

A. Hand length, hand width and size

Table I summarizes the hand anthropometric data of the subjects. The mean of 15 subjects for hand length is 17.6cm, hand width 8.53cm and hand area is 149.5cm^2. The mean of each dependent variable for male subjects was consistently higher than female subjects.

TABLE I. HAND ANTHROPOMETRIC DATA

Measure	All subjects		Male		Female	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Hand length (cm)	17.6	1.71	18.21	1.94	16.91	1.19
Hand width (cm)	8.53	1.43	9.31	1.22	7.64	1.13
Hand size (cm^2)	149.5	37.65	171.1	37.79	124.73	23.21

B. Inside grip diameter

Table II shows the descriptive statistics of the inside grip diameter (grouped by all subjects, male and female). The mean of male subjects is 4.23cm higher than the mean of female which is 3.57cm.

TABLE II. INSIDE GRIP DIAMETER

Measure	All subjects		Male		Female	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Grip diameter (cm)	3.92	0.50	4.23	0.39	3.57	0.36

C. Hand grip strength

Table III shows the mean value of male subjects was 33.25kg higher than the mean value obtained by female subjects which was 15.14kg. This result shows a similar finding of a previous study [21]. Variation of grip strength between the genders is due to male has larger body size and muscle mass which can produce greater grip strength compared to female [12].

The grip strength obtained in this study was compared to a recent study among Malaysian elderly [22]. It seems that the results obtained by this study were consistent with the study in [22], in which male produced greater grip strength compared to female subjects.

TABLE III. HAND GRIP STRENGTH

Measure	All subjects		Male		Female	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Grip strength (kg)	24.80	11.43	33.25	8.35	15.14	4.45

D. Hand surface area and contact area

Table IV depicts the measurement results of hand surface area and contact area for all subjects when using 3 different designs of walking stick handle. The average of all subjects' contact area applied to handle A was 62.86cm^2, higher than handle B and handle C. Meanwhile the contact area of handle B was 61.55cm^2, slightly higher than C (61.14cm^2). The trend of findings was also similar to male subjects. It shows that the contact area of handle A was the highest (68.24cm^2), handle B was 65.84cm^2 and handle C was 65.77cm^2. Among female subjects, the result shows that the contact area of handle A (56.70cm^2) was higher than handle B (56.65cm^2) and handle C (55.85cm^2). Based on these findings, it is clearly shown that the contact area of handle A was larger than handle B, and handle B's contact area was larger than handle C.

TABLE IV. HAND SURFACE AREA AND CONTACT AREA

Measure	All subjects		Male		Female	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Hand surface area	74.66	18.31	78.51	22.94	70.27	11.22
Contact area handle A	62.86	17.87	68.24	21.00	56.70	12.13
Contact area handle B	61.55	16.54	65.84	20.54	56.65	9.68
Contact area handle C	61.14	17.80	65.77	21.57	55.85	11.61

E. Effect of hand size on grip strength

Early assumption indicates that the grip strength increased with the increasing of hand size [13], [23]. This is due to individuals with a bigger hand tends to have greater muscular strength for gripping force [20]. This study found that a positive relationship between hand size and grip strength ($R^2 = 61.7\%$) and statistically significant with p-value < 0.05. However, in this study, not every large hand size produces greater grip strength. Several factors may contribute to this finding such as the factor of age and muscle weakness [10].

A negative relationship was found between grip strength and age. As the age increased, the subject's capability to produce grip strength becomes decrease due to muscle weakness. The negative relationship between grip strength and age among male subjects shows the $R^2 = 36.4\%$ with a p-value > 0.05 and female subjects, the $R^2 = 34.2\%$ with a p-value > 0.05. In some cases, the increasing of age is not definitely producing less grip strength. The declining trend of grip strength among female subjects based on age factor is consistent with the findings of previous studies [21], [22].

Based on the literature, the previous occupation of the subjects might contribute to the variations of grip strength. Subjects who performed the manual operation in their previous occupation show greater grip strength, compared to the skilled and sedentary occupation. This is due to manual jobs can strengthen the hand muscles. However, this study found that there was no significant difference between the grip strength and the previous occupation of the subjects (p-value > 0.05). This is in line with the findings of the previous study, in which the occupation background did not influence the individual's grip strength [22].

F. Effect of inside grip diameter on grip strength

This study found that the hand length has a positive relationship with the inside grip diameter with $R^2 = 63.4\%$ and statistically significant with p-value < 0.05. This suggests that most subjects with long hands tend to have greater inside grip diameter. The finding is quite similar to study in the literature whereby male and female adults have larger inside grip diameter with the increased of hand length [24]. Another study found that wider palm breadth, the larger the inside grip diameter [16]. Logically, when a subject has a larger size of inside grip diameter, he or she has more capability to perform maximum gripping force. This statement is supported by past studies, the best way of power gripping should be in the range of inside grip diameter of the subjects [15], [25].

The inside grip diameter is most likely having an effect towards grip strength performance. A positive relationship was identified between the inside grip diameter and the hand grip strength with $R^2 = 43.8\%$ and statistically significant with p-value < 0.05. This means having a greater inside grip diameter would lead to greater grip strength. For instance, maximum grip strength is required while using a handsaw in sawing activity. To do that, the handsaw handle must fit with the users' inside grip diameter so that the users can generate maximum force to grip the handle.

However, in this study, there are several subjects having a large inside grip diameter but produce less amount of grip strength. It may due to their capability to generate maximum grip force was influenced by other factors such as age and muscles weakness [10].

G. Effect of hand size and handle shape on the contact area

Analysis between the hand size and the hand surface area shows a linear relationship with $R^2 = 54\%$ and statistically significant with p-value < 0.05. As for the relationship between the contact area of the handle and hand size, a linear relationship was found with $R^2 = 53.3\%$ for handle A, $R^2 = 46.5\%$ for handle B, and $R^2 = 36.6\%$ for handle C. The positive relationship was statistically significant at α-level of 0.05. However, there were subjects with large hand size that did not significantly contribute to the large hand surface area. This is due to the thickness of fat pads on the palmar side for an individual is different from one to another. For instance, a subject with thin palm tends to have a gap at the centre of the palmar side when they placing their hand on a flat surface.

The same situation also applied when a thin palm gripping the handle. It creates a gap between the palmar side and the handle surface which then resulted in less contact area on the handle. The diameter of the handle also contributed to the gap between the handle and the hand. This finding has a good agreement with the past study whereby the diameter of handle determined the gap at the centre of the palmar side [13].

Out of 15, 10 subjects produced large contact area on the handle A followed by handle B and handle C. By looking at the handle shape characteristic, handle A has more advantages compared to handle B and C. It has a straight and circular shape which is easier to grip and the subjects can grip it without creating a huge gap between the palmar side and the handle surface. As for handle C, although it has a circular diameter the curve-shape does not provide a large contact area because the contact point is concentrated on the top side of the handle (Fig. 4).

Fig. 4. Handle C. The contact point is concentrated on the top side

The handle B was rectangular curve (Fig. 5). Although it looks like having an ergonomic design and aesthetic value, however, the curvy top surface did not contribute to a large contact area for gripping the handle. Palm and finger sizes of each subject were different thus not all hands can fit this handle design. It creates a huge gap between the palmar side and the handle surface which resulted in less contact area. An established study pointed out that the handle curvature interferes the interaction between the user's hand and the stick in terms of contact area and pressure concentration. This can affect individual comfort [26].

Fig. 5. Handle B - curvature shape

IV. CONCLUSION

This study measured the hand parameters such as length, width, inside grip diameter, hand surface area, contact area and grip strength among elderly Malaysian. In relation to the hand parameters, this study was also evaluated three designs of walking stick handle which available in the market.

The study discovered that the grip strength increased with the increasing of hand size. There was a positive relationship between the hand size and the grip strength for both male and female subjects. However, the study found that there was a negative relationship between the grip strength and their age.

It also found that hand length has a positive relationship with inside grip diameter. This suggests that most subjects with longer hand tend to have greater inside grip diameter. Inside grip diameter has a positive correlation with the palm breadth. Wider the palm breadth, the larger the inside grip diameter. The inside grip diameter is most likely having an effect towards grip strength performance. It showed a positive relationship exists between the inside grip diameter and grip strength. This means having a greater inside grip diameter would lead to having a better grip strength.

Three walking sticks design that commonly used by elderly Malaysian was identified i.e. Swan-neck (handle A), T handle (handle B) and Crook handle (handle C). The parameters of hand were measured based on these walking sticks. The study found that walking stick with handle design A has better accomplishment compared to the other two designs. The justifications were based on the contact area between the hand and the stick handle. Handle A was round and padded with a soft cushion. It provides a higher contact area and the grip pressure is uniformly distributed along the handle.

Besides the hand grip part, future studies are suggested to examine the effects of end tip design to increase body stability of elderly when using the walking stick.

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