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*Original research article*

# Differences in Grip Strength among Wheelchair Basketball Athletes: Variations by Hand Size and Handrim-Tire Diameter

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## ABSTRACT

Wheelchair basketball is a popular sport for people with disabilities. Movement skills during competition require a suitable grip with the wheelchair wheels. An inappropriate handgrip may reduce performance. The objective of this study was to investigate the effect of 3 handrim-tire diameters on the handgrip strength in 3 hand sizes of wheelchair basketball athletes. Seventy-one wheelchair basketball athletes, 20-40 years old, with a Functions Determining Classification level of 1.0-4.5, and who have played wheelchair basketball for more than 1 year, were divided into 3 hand size groups; small (≤180 mm.), medium (190-200 mm.), and large (≥230 mm.). Handgrip strength, local perceived discomfort, and comfort questionnaire for using hand tools were recorded for 3 handrim-tire diameters; 63 mm., 67 mm., and 71 mm. Descriptive data analysis and two-ways mixed-model ANOVA were used to analyze the data, including a posthoc analysis with Tukey's test. The highest grip strength for small, medium, and large hands was found for handrim sizes of 63, 67, and 71 mm., respectively. Grip strength for medium hand size was significantly higher when compared to small hand size in 3 handrim-tire diameters ($p<0.01$, $p<0.001$, $p<0.001$, respectively). Large hand size was significantly higher when compared to small hand size in handrim-tire 67 mm. ($p<0.001$) and 71 mm. ($p<0.001$). High discomfort was found for the following: small hand size with handrim-tire 67 and 71 mm., medium hand size with handrim-tire 63 mm., and large

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hand size with handrim-tire 63 and 67 mm. Handgrip strength and hand discomfort in each hand size were correlated to handrim-tire diameter.
**Keywords:** Hand size; Wheelchair basketball; Handrim; Handrim-tire distance; Grip strength

## 1. Introduction

Wheelchair basketball is one of the most popular sports for persons with a wide range of disabilities, from lower limb amputees to high-level spinal cord injuries causing some dexterity limitations in the legs and feet. The array of wheelchair sports is expanding, and increasing in visibility each year. Wheelchair basketball athletes who participate in wheelchair sports benefit from their competitive and recreational pursuits. Currently, the sport is played in more than 100 countries [1] and played on national and international stages, including the Paralympic Games [2]. The basic skills of wheelchair basketball are similar to those found in stand-up basketball with only a few modifications. Wheelchair movement skill activities use different movement skills, such as, starting and stopping in the wheelchair, pushing the wheelchair forward, accelerating quickly, maintaining speed, , and turning and changing directions.

The specific skills for playing wheelchair basketball are shooting, passing, dribbling, rebounding, catching, blocking, and contacting [3]. Wheelchair basketball players cover a distance of approximately 2679. 52 m per game, traveling at about 1. 48 m per second on average, and stopping 239. 78 times on average, per game [4]. Because there are many movements possible in wheelchair basketball, the repetitive nature of these movements can lead to injury [5]. The most frequently injured body parts are the shoulders, wrists, and lower back [6]. About 72% of injuries are caused by wheelchairs [7]. Driving a wheelchair can be divided into 2 phases: push phase and recovery phase [8]. The wheelchair movement is a result of the activity of the muscles [9]. All movement skills require good and appropriate handgrips with a wheelchair wheel.

A study of the handgrip of wheelchair users showed that 54.5% grip handrim and tire at the same time, 39% grip only the handrim, and 6.5% grip only the tire [10]. However, players of other wheelchair sports tend to grip only the handrim. The large tube diameter yielded slightly but significantly lower values for the physiological parameters [11]. Gross mechanical efficiency was on average 7% for the large tube diameter and 6.3% for the small tube diameter [12, 13] and it was shown that grip moments were reduced with the natural fit handrim (NF) prototype as compared with the subjects' current handrim. There was an improvement in the ease of wheelchair propulsion and a reduction of pain in the hands and wrists. Additionally, subjective scores rating the handrims proved significantly different between the round rubber coated handrim and the narrow rubber-coated flat profiled handrim [14]. Data from fieldwork and personal communication found that the handrim-tire from the factory was only available in one size and did not fit all players; the athletes would need to adjust the handrim-tire themselves for a better grip. Moreover, previous studies focused only on shape diameter [11, 12, 13], and material of the handrim, including satisfaction in using the handrim [14], but there is still a lack of data on the effect hand size and handrim-tire diameter has on grip strength and discomfort level in wheelchair athletes. Therefore, the objective of this study was to investigate the effect of handrim-tire diameter on handgrip strength, in 3 hand sizes, of wheelchair basketball athletes.

## 2. Materials and Methods

### 2.1 Participants

Current wheelchair basketball players were recruited from The Wheelchair Basketball Association of Thailand, wheelchair basketball sports teams, The National Disability Training Center, and Mahatai school, in January 2017. Screening tests and data collection were done at The Wheelchair Basketball Association of Thailand. Ninety-two invitation letters with research information were sent to all wheelchair basketball players. Eighty-four wheelchair basketball players agreed to participate and came to the screening site. Seventy-five of these wheelchair basketball players fulfilled the inclusion criteria. Three players did not pass the exclusion criteria and one player did not come on the appointment day.

The seventy-one participants were male, aged 20-40 years, had normal hand and arm movement, played wheelchair basketball for at least 1 year, and had no other abnormalities in their nervous system. Participants who could not clasp their hands, had an acute injury, a musculoskeletal disorder in their arms and hands (at least 1 week), or had performed strenuous exercise 48 hours before the test were excluded from the study. All subjects read and signed a consent form before participating in the study. The research protocol was approved by the Thammasat University Human Research Ethics Committee (No.045/2559).

### 2.2 Experimental design

Anthropometric measurements were collected from the dominant hand of each subject [15]. Muscle stretching and evaluation of handgrip strength was taken in three handrim-tire diameters (63, 67, and 71 mm.). A handrim-tire diameter of 67 mm. was the standard handrim-tire and commercially available. Data from the anthropometric measurements was used to divide hand length into 3 hand sizes: small (≤180 mm.), medium (190-200 mm.), and large (≥ 230 mm.). A handgrip dynamometer (Takei T.K.K.5401 GRIP-D, Takei Scientific Instruments Co., Ltd, Tokyo, Japan) was used for handgrip strength measurement. Each participant was asked to squeeze the dynamometer with his dominant hand at maximum effort 3 times, resting for 30 seconds between each measurement, these 3 measurements were averaged; then, the athlete would rest 60 seconds before starting another trial. The participant was seated in their wheelchair with their arm fully extended beside their body. The shoulder adducted, flexion 0° and neutrally rotated, elbow fully extended, forearm in neutral, and wrist between 0°-30° of extension [16, 17]. Local perceived discomfort (LPD) of arm and hand was measured immediately after each task by using a detailed hand-wrist map, with 23 regions, and an arm map which consisted of two regions. A 6-point Likert scale was used to assess discomfort ranging from 0 (comfort), 1 (very little discomfort), 2 (moderate discomfort), 3 (high discomfort), 4 (very high discomfort), and 5 (extreme discomfort).

The Modified Comfort Questionnaire for Hand tools (CQH) was used to evaluate comfortability, productivity, and ease of use [18]. The modified CQH composed of 21 questions in 4 areas; 1) grip characteristics, 2) physical interaction, 3) effect on the body, and 4) shape and usability. It had a 7-point Likert scale (1 = totally disagree, to 7 = totally agree). The questionnaire was developed based on the results of a previous study in which descriptors associated with comfort in using screwdrivers were identified by end-users, like 'fits the hand', 'has good functionality', and 'offers a high task performance'.

Data were analyzed with Statistical Package for Social Sciences (SPSS) version 22.0 (SPSS Inc., Chicago, IL, USA). Descriptive data analysis was used to analyze data for general characteristics, LPD, and The CQH. Two-ways mixed-model ANOVA was used to determine handgrip strength both within and between groups in handgrip strength analysis. Post-hoc analysis was performed using Tukey's Test. The significance level was set at 0.05.

## 3. Results and Discussion

### 3.1 Results

The characteristics of the 71 participants included in this study are as follows: age29.45 ± 7.4 years, height 167.79 ± 10.01 cm, weight 59.48 ± 14.17 kg, wheelchair-experience 8. 25 ± 7. 9 years, wheelchair basketball experience 7. 11 ± 7. 4 years, and competitive basketball experience 6. 27 ± 6. 3 years (Table 1). Participants had different levels of disability and a variety of pathologies. Some participants were amputee athletes and had no wheelchair experience in their daily life. Half of the participants had spinal cord injuries and a Functions Determining Classification level greater or equal to 3.0 in The International Wheelchair Basketball Federation classification (IWBF classification). Many of the participants played in the position of point guard or center positions.

Table 2 shows the handgrip strength in 3 hand sizes when using 3 handrim-tire diameters. The small hand size had the highest handgrip strength with a handrim-tire size of 63 mm (37.62 ± 8.52 kg). The highest handgrip strength for the medium hand size was with a handrim-tire size of 67 mm (46.73 ± 8.07 kg),while the large hand size had the highest handgrip strength with a handrim-tire size of 71 mm (52.60 ± 7.54 kg).

Muscle strength in small hand size increased significantly in the 63 mm handrim-tire when compared to the 67 mm ($p$<0.01) and 71 mm handrim-tire ($p$<0.001). Muscle strength in medium hand size increased significantly in the 67 mm handrim-tire when compared to the 63 mm handrim-tire ($p$<0.001), but no difference for the 71 mm handrim-tire. While large hand size strength was significantly greater with the 71 mm handrim-tire when compared to the 63 mm handrim-tire ($p$<0.001) but there was no significant change when compared to the 67 mm handrim-tire.

When comparing muscle strength among 3 hand sizes, handgrip strength in medium hand size was significantly greater than small hands using handrim-tire sizes 63 mm, 67 mm, and 71 mm ($p$<0.01, $p$<0.001, $p$<0.001, respectively). While the large hand size was significantly greater than small hands using handrim-tire sizes 63 mm, 67 mm, and 71 mm ($p$<0.05, $p$<0.01, $p$<0.01, respectively).

Moderate to high LPD after using 3 handrim-tire diameters in 3 hand sizes are shown in Fig. 1., very high discomfort and extreme discomfort were not found in this study. In small hand sizes, comfortable and mild discomfort was found after using handrim-tire sizes of diameter 63, 67, and 71 mm. (88.39, 73.46, 69.65%; respectively).

Moderate discomfort was found in the 63 mm handrim-tire (11.61%) at the middle phalanges (index, middle, ring, and little fingers) and proximal phalanges (middle and ring fingers), and palmar area.

High discomfort was found in the 67 mm handrim-tire (5.86%) at the middle phalanges (index, middle, ring, little finger) and palmar area. Moderate discomfort (20.68%) was found at the distal phalanges (index, little finger) and palmar area.

For the 71 mm handrim-tire, a high discomfort level of 3.78% was found at the middle phalanges (index, middle, ring fingers) and palmar areas. A moderate discomfort level (26.56%) was found at distal phalanges (index, middle, ring, little finger), and the middle phalanges (little finger).

In medium hand size, comfort and mild discomfort was found after using handrim-tire sizes of diameter 63, 67, and 71 mm (74.1, 81.73, 76.67%; respectively).

High discomfort was found with the 63 mm handrim-tire (5.12%) at the middle phalanges (index and middle fingers) and proximal phalanges (middle and ring fingers). While moderate discomfort (20.78%) was found at the middle phalanges (ring and little fingers) and distal phalanges (index and little fingers).

Moderate discomfort was found after using the 67 mm handrim-tire (18.28%) at the middle phalanges (index, middle, ring, and little fingers), distal phalanges (index finger), and palmar area.

A high discomfort was found after using the 71 mm handrim-tire (4.10%) at the middle phalanges (index, middle, and ring fingers), distal phalanges (index and little fingers), and palmar area. Moderate discomfort (19.23%) was found at the middle phalanges (little finger), distal phalanges (middle and ring fingers), and palmar area.

For large hand size, comfort and mild discomfort (level 0-1) were found after using handrim-tire sizes of diameter 63, 67, and 71 mm (0, 66.7, 75.02%; respectively).

High discomfort was found after using the 63 mm handrim-tire (58.35%) at middle phalanges (index, middle, ring, and little fingers), proximal phalanges (middle and ring fingers), and palmar area. While moderate discomfort (41.65%) was found at the middle phalanges (index, middle, ring, and little fingers), proximal phalanges (middle and ring fingers), and palmar area.

Moderate discomfort from the 67 mm handrim-tire (33.30%) was found at the middle phalanges (index, middle, ring, and little fingers) and palmar area.

Moreover, moderate discomfort was also found from the 71 mm handrim-tire (24.98%) at the middle phalanges (index, middle, and ring fingers), distal phalange (little finger), and palmar area.

The Comfort Questionnaire for hand tools showed details about comfortability, productivity, and ease of use while using different handrim-tire sizes in each hand size. Most participants in the three hand sizes answered ‘totally disagree’ with all topics in the effect on body component.

For the shape and usability component, most small hand size participants answered 'strongly agree’ and ‘totally agree’ when using a 63 mm handrim-tire (44.80%), 67 mm handrim-tire (51.70%), and 71 mm handrim-tire (40.88%), they answered ‘totally disagree’ or ‘mild disagree’.

In contrast, most of the medium hand size participants answered ‘strongly agree’ and ‘totally agree’ when they used a 67 mm handrim-tire (44.70%). Participants answered 'totally disagree’ or ‘mild disagree’ when using a 63 mm handrim-tire (41.03%) and a 71 mm handrim-tire (40.29%). But in large hand size participants, all answered ‘totally agree’ while using a 71 mm handrim-tire (47.61%) and had varied agreement while using the other handrim-tire diameters (49.99%).

Small hand size participants answered ‘strongly agree’ (scales 6-7) when using a 63 mm handrim-tire (44.80%). In the grip characteristics component, 62% answered ‘totally disagree' and 'disagree' on the topic "the distance of the handrim is too far from the wheel".

While using the 71 mm handrim-tire, 68% answered 'totally agree' on the topic “the distance of the handrim is too far from the wheel”. Also, they complained “a lot of muscle exertion to proportion” when using a 67mm handrim-tire (53.97%) and a 71 mm handrim-tire

(58.60%) in the physical interaction component.

Medium hand size participants answered ‘strongly agree’ (scales 6-7) for using the 67mm handrim-tire (44.70%). In the grip characteristics component, 66% answered ‘totally disagree' and 'disagree' on the topic "the distance of the handrim is too far from the wheel".

When using a 63 mm handrim-tire, 61% answered 'totally agree' on the topic “the distance of the handrim is too close to the wheel” and 84% answered ‘totally agree’ on the topic “the distance of the handrim is too far from the wheel” while using a 71mm handrim-tire. Moreover, the physical interaction component produced many “a lot of muscle exertion to proportion” responses when using handrim-tire diameters 63 mm (63.27%) and 67 mm (87.17%).

Large hand size participants answered 'strongly agree' (scales 6-7) when using a 67 mm handrim-tire (52.37%). In the grip characteristics component, 66% answered ‘totally disagree' and 'disagree' on the topic "the distance of the handrim is too far from the wheel" when using a 71 mm handrim-tire.

In the 63 mm handrim-tire, 66% answered ‘totally agree’ on topic “distance of the handrim is too close to the wheel”. In the physical interaction component, 44.43% of participants answered “a lot of muscle exertion to proportion" when using a 63 mm handrim-tire.

**Table 1.** General characteristics of wheelchair basketball athletes.

| Participants’ data | | Total (n=71) | Small hand (n=29) | Medium hand (n=39) | Large hand (n=3) |
|---|---|---|---|---|---|
| Age (years) | mean ± SD<br>(min-max) | 29.45 ± 7.4<br>20-40 | 28.97±7.35<br>20-40 | 29.69±7.64<br>20-40 | 31.00±6.56<br>24-37 |
| Weight (kg.) | mean ± SD<br>(min-max) | 59.48 ± 14.17<br>32-103 | 53.21±10.61<br>35-72 | 63.76±15.21<br>32-103 | 64.66±9.50<br>55-74 |
| Wheelchair basketball experience (years) | mean ± SD<br>(min-max) | 7.11 ± 7.4<br>1-28 | 6.41±6.56<br>1-20 | 7.08±7.85<br>1-28 | 14.33±6.66<br>10 -22 |
| Wheelchair-experience in daily life (years) | mean ± SD<br>(min-max) | 8.25 ± 7.9<br>0-26 | 10.00±7.31<br>0-23 | 7.23±8.29<br>0-26 | 4.67±6.42<br>0-12 |
| Competition-experience (years) | mean ± SD<br>(min-max) | 6.27 ± 6.3<br>0-20 | 5.78±6.11<br>0-20 | 6.26±6.43<br>0-20 | 11.00±7.94<br>2-20 |
| Hand Length (mm.) | mean ± SD<br>(min-max) | 188.8 ± 14.02<br>165-240 | 176.24±4.51<br>165-180 | 194.15±3.83<br>190-200 | 236.67±5.77<br>230-240 |
| Palm Length (mm.) | mean ± SD<br>(min-max) | 108.87±6.13<br>96-123 | 103.62±4.51<br>96-120 | 112.08±3.94<br>104-122 | 118.0±3.00<br>115-123 |
| Forearm length (mm.) | mean ± SD<br>(min-max) | 456.58±32.74<br>305-497 | 432.69±37.35<br>305-475 | 471.90±13.70<br>447-496 | 488.33±7.51<br>484-497 |

| Participants’ data | | Frequency (n=71) | Percent |
|---|---|---|---|
| Pathology | Spinal cord injury (T) | 21 | 29.6 |
| | Spinal cord injury (L) | 13 | 18.3 |
| | Spinal cord injury (S) | 2 | 2.8 |
| | Amputation | 15 | 21.1 |
| | Poliomyelitis | 13 | 18.3 |
| | Others | 7 | 9.9 |
| IWBF classification | Classification 1.0 | 12 | 16.9 |
| | Classification 2.0 | 7 | 9.9 |
| | Classification 3.0 | 18 | 25.4 |
| | Classification 4.0 | 13 | 18.3 |
| | Classification 4.5 | 3 | 4.2 |
| | Others classification | 10 | 14.1 |
| | Unable to classify due to forgetting classification level | 8 | 11.3 |
| Wheelchair Basketball Position | Point guard | 24 | 33.8 |
| | Shooting guard | 8 | 11.3 |
| | Power forward | 3 | 4.2 |
| | Center | 22 | 31.0 |
| | Small forward | 11 | 15.5 |
| | Others | 3 | 4.2 |

**Table 2.** Handgrip strength in 3 hand sizes; small, medium, and large during use of 3 handrim-tire diameters.

| Handgrip strength (kg) | Handrim-tire diameter 63 mm | Handrim-tire diameter 67 mm | Handrim-tire diameter 71 mm |
|---|---|---|---|
| **Small hand (n=29)** | | | |
| **mean±SD** | $37.62 \pm 8.52^{bb}$ | $36.49 \pm 8.28$ | $34.22 \pm 8.47^{aaa, bbb}$ |
| **min-max** | 19.4 – 54.8 | 18.0 – 47.9 | 13.9 – 46.1 |
| **Medium hand (n=39)** | | | |
| **mean±SD** | $44.84 \pm 8.28^{**, bbb}$ | $46.73 \pm 8.07^{***}$ | $46.41 \pm 9.74^{***}$ |
| **min-max** | 19.5 – 63.5 | 21.2 – 65.3 | 15.1 – 66.2 |
| **Large hand (n=3)** | | | |
| **mean±SD** | $47.73 \pm 7.09^{*}$ | $50.00 \pm 7.38^{**}$ | $52.60 \pm 7.54^{**, aa}$ |
| **min-max** | 41.6 – 55.5 | 43.9 – 58.2 | 44.2 – 58.8 |

$^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$ when compared with small hand (hand length ≤ 180 mm.)
$^{a}p<0.05$, $^{aa}p<0.01$, $^{aaa}p<0.001$ when compared with Handrim-tire diameter 63 mm
$^{b}p<0.05$, $^{bb}p<0.01$, $^{bbb}p<0.001$ when compared with Handrim-tire diameter 67 mm

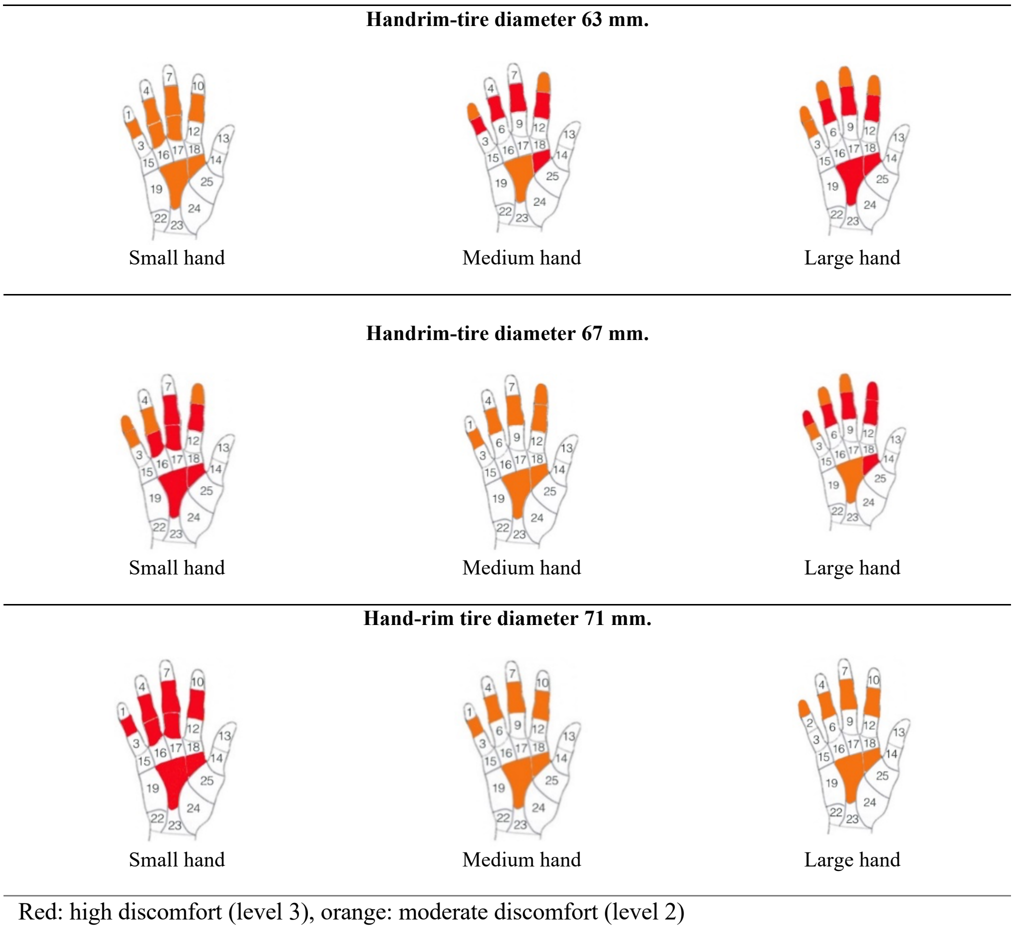


**Fig. 1.** Moderate to high local perceived discomfort in 3 hand sizes after use of 3 handrim-tire diameters.

### 3.2 Discussion

The results of this study show the effect of handrim-tire diameter and hand length on maximum handgrip strength, local perceived discomfort of hand, comfortability, productivity, and ease of use from Comfort Questionnaire for the hand tool in wheelchair basketball athletes. The suitable handrim-tire diameter was analyzed for handgrip strength, local perceived discomfort of hand, and data from the Comfort Questionnaire for the hand tool.

Muscle strength in small hands was significantly greater when gripping a 63 mm handrim-tire. While muscle strength in medium and large hands was significantly greater when gripping handrim-tire sizes 67 and71 mm. This indicated that a small hand gains more muscle force while using a handrim tire of small diameter. In contrast, medium and large hands had low muscle force when gripping handrim-tires of diameter. This may be due to an improper grip that hinders the muscle's ability to generate force during performance tests.

Medium and large hand sizes had higher handgrip strength than the small hand size in all 3 handrim-tire diameters (Table 2). This may be due to differences in muscle and body size that generate muscle force during handgrip strength testing.

Handrim-tires with a diameter of 63 mm seemed suitable for small hand sizes. This group had the highest handgrip strength with 63 mm handrim-tires, moderate discomfort was found, and when surveyed, participants answered'strongly agree' (scales 6-7) in shape and usability, physical interaction, effect on the body, and grip characteristics.

Moreover, moderate to high discomfort (level 2-3) was found in handrim-tire diameters 67 and 71 mm. The Comfort Questionnaire for hand tool in handrim tire diameter 71 mm indicated that there were some problems in comfort, productivity, and ease of use such as the answers for the topics 'the distance of the handrim was too far from the wheel' and 'had a lot of muscle exertion to propulsion'.

The medium hand size group seemed to be best suited using a handrim-tire of diameter 67 mm, maximum handgrip strength was higher when compared to the other diameters, and a moderate discomfort level was found. The Comfort Questionnaire for hand tool during the gripping of the 67 mm handrim-tire found 'strongly agree' (scales 6-7) in shape and usability, physical interaction, effect on the body, and grip characteristics. The maximum handgrip strength was less when using the 67 mm handrim-tire and a moderate to high discomfort level was found during the handgrip test while using handrim-tire diameters 63 and 71 mm. Moreover, the Comfort Questionnaire for hand tool found that the distance of the handrim was too close to the wheel in handrim-tire diameter 63 mm, and at 71 mm the distance of the handrim was too far from the wheel. A high ratio of muscle exertion to propulsion was found during use of handrim-tire diameters 63 and 71 mm.

The large hand size seemed to be best suited using handrim-tire diameters 67 or 71 mm. The maximum handgrip strength was higher whileusing handrim-tire diameters 67 or 71 mm and comfort and mild discomfort levels were found. Moreover, participants answered 'strongly agree' (scales 6-7) in shape and usability, physical interaction, the effect on the body, and grip characteristics, with a handrim-tire diameter of 67 mm. While for the 63 mm size, the distance of the handrim was too close to the wheel and participants experienced a high ratio of muscle exertion to propulsion .

In this study, moderate to high discomfort in 4 fingers (proximal and middle phalanges) and palmar areas was found. The middle phalanges and palm were the areas that had high pressure and were affected directly while gripping the handrim-tire. Decreased grip strength may be due to discomfort in the fingers.

Maximum handgrip strength at different handrim-tire diameters from increased or decreased muscle power may be affected by the activity of forearm and intrinsic hand muscles [19], especially the finger flexor muscle that produces grip force. A suitable and proper grip provides an increased mechanical advantage for the index finger on a fixed point.

The evaluation of comfort or discomfort is mostly based on the participants' judgment. Comfort can contribute to task performance. A proper handrim-tire grip decreased discomfort and participants felt better during use. The usability of hand tools is mostly accompanied by a feeling of discomfort. When discomfort is present, it must be avoided by optimization of the shape and usability and physical interaction. Diruf, et al. (2008) found that simple modification of the wheelchair can help bring about significant change in the user experience, for both symptoms and function. It was reported that 85% of respondents reported less pain in their hands and 80% reported less pain in their wrists [12].

There were few studies in wheelchair sports, some studied handrim diameter [11, 12, 13], the shape of handrim [14], however, no paper has studied the handrim-tire distance. LPD of the arm and hand during the handgrip test at different handrim diameters increased or decreased muscle power of the intrinsic hand muscles [19].

Results from the maximum handgrip strength in this study were different from previous studies [13]. This difference may be due to the different characteristics of participants. They were done in healthy adults that showed differences of anthropometric variables, such as hand length and hand width, which positively associated with handgrip strength [20]. Moreover, increases in efficiency of propelling, the comfort of propelling, decrease in fatigue, pain in the hand and wrist were all found in the studies when changing the grip shape. Using an ill-fitting handrim may result in a higher risk of injury; 79% of participants had pain in the upper limb [6,7], 33% had soft tissue injury [21], and 72% of subjects reported pain since wheelchair use [8].

## 4. Conclusions

Our results suggest that those with a small hand size are is best suited using a handrim-tire diameter of 63 mm, a medium hand size using a handrim-tire diameterof 67 mm, and a large hand size using a handrim-tire diameter of 67-71 mm. Appropriate grip with handrim-tire diameter might reduce fatigue, risk of musculoskeletal injury, and feel more comfortable to use while playing wheelchair basketball.

## 5. Limitation of the study

In this study, there was a small number of large hand size athletes (only 3 participants). The interpretation and application of this data should be done carefully. Further studies should recruit a larger number of participants in the large hand size category to define the most suitable handrim-tire diameters. Another limitation was that there was no muscle activity information in different handrim-tire diameters for sports performance, which cannot explain details of local perceived discomfort of arm and hand.

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