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Analysis of hand pressures related to wheelchair rim sizes and upper-limb movement

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ABSTRACT

Hand pressure is important in wheelchair design as it is directly related to the comfort or injury of the patients/sportsmen using the wheelchair. However, little research has been done on hand pressure during wheelchair propelling. This study aimed to measure hand pressures and joint movements in the upper limb with the different size of wheelchair rims during manual propulsion. Nine healthy adult subjects participated in the study, and they were required to perform wheelchair propelling at their self-comfortable way. A specific mat of pressure sensors was used to measure the hand pressure of the palm and a motion capture system to capture the movements at the shoulder and elbow. The results showed that under the condition of the speeds between 0.7–1.7 m/s, the mean hand pressures were ranged between 180 and 200 kPa on the palm; the ranges of motion were from 30° to 70° at the shoulder and from 15° to 50° at the elbow. The pressure and kinematic data collected provide a set of database available for wheelchair manufacturer, glove designer, clinicians and sports exerciser as reference when they need.

Relevance to industry: Pushing wheelchair usually causes hand uncomfortable or injury. Our study provides the first experimental data of hand pressures associated the joint movements in the upper limbs at different sizes of push-rims. These results are valuable for devising gloves for patients, thus improving the life quality of the patients using wheelchair.

1. Introduction

A wheelchair is an integral device for people with lower limb disabilities as it provides mobility and independence (Tsai et al., 2008). However, pushing the hand rim of a manual wheel frequently leads to low mechanical efficiency as it is physically demanding. Although some studies have analysed the effect of hand-rim on manual wheelchair propulsion (Guo et al., 2006; Richter et al., 2006; Van Der Woude et al., 1988) and seating conditions (Gaudez et al., 2008; Haynes and Williams, 2008), little research investigated hand pressure during wheelchair propelling and associated rim sizes and upper limb joint movement; an understanding of hand pressure would benefit patient comfort and may provide clues to better wheelchair design.

Guo et al. (2006) examined the effect of hand rim size on mechanical energy and power flow during wheelchair propulsion and reported that any increase in hand-rim size also increased the total energy consumption of the upper extremity. Richter et al. (2006) concluded that the finger and wrist flexor activity was lower when pushing with a high friction flexible hand rim than with a standard uncoated hand rim. Van Der Woude et al. (1988) investigated the effects of various hand-rim diameters on physiological and movement parameters. They concluded that because of lower linear hand velocity and reduced movements of the shoulder and elbow joint, propelling a smaller hand-rim had a higher mechanical efficiency.

Fransson and Kilbon (1993) demonstrated that subcutaneous fat distributed over a large area of the hand, along with palmer fascia, acts as a pressure-absorbent. Hence, where the subcutaneous fat is thin, pressure is mainly absorbed by flexor tendons and their sheaths leading to high pressure areas. The degree of sensitivity was found to be the greatest in the thenar area followed by the palmar and the finger regions. Johansson et al. (1999) came to the same conclusion in a similar study design.

To identify the contact forces and localised pressure peaks, Aldien et al. (2005) used three different cylindrical handle sizes in

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their study of ten healthy subjects. Contact pressure was found to be the highest at the hand–handle interface with peak pressure depending on handle-size, grip and push forces; the thenar eminence being the most susceptible to this pressure.

Analysis of shoulder and elbow motion at different speeds (1.3 and 2.2 m/s) of wheelchair propulsion was conducted by Boninger et al. (1998). The authors recorded data on shoulder flexion/extension and adduction/abduction and the elbow flexion/extension. Though some studies reported the wheelchair speeds and the movements in the shoulder and elbow (Collinger et al., 2008; Veeger et al., 1992), they did not associate the movement data with hand pressures.

Previous studies have reported different hand forces and pressures in different situations, e.g. hand forces in griping cylindrical handles (Aldien et al., 2005), max griping strengths (Rossi et al., 2012), and male griping strength (Seo et al., 2007); also the pressures in handgrip measurements (Ugurlu and Ozdogan, 2011) and in falling down (Choi and Robinovitch, 2011). However, there was little research directly measuring hand pressures on the wheelchair rim.

The present study aimed to investigate hand pressures and upper limb joint movements using different sized wheelchair rims during wheelchair propulsion. The amount and distribution of pressure areas over the palm with respective joint movements produced could help manufacturers in the design of wheelchairs and gloves, thus improve the quality of life of wheelchair users.

2. Methods and materials

2.1. Participants

Nine healthy volunteers participated in this study aged between 21 and 41 years (Mean: 32.5, Standard Deviation, S.D., 7.08), eight males and 1 female. They had a mean height of 175.5 cm (S.D. 6.4) and a mean weight of 77.0 kg (S.D. 12.6). The volunteers had no history of shoulder or elbow injury and absence of any current or previous motor deficit or surgeries to the upper limbs. The study was approved by the university research ethics committee. All subjects signed the consent forms prior to data collection.

2.2. Protocol

A standard wheelchair (Lomax® Ltd, the seat size of 470 × 450 mm in width by depth and the seat height at 500 mm from the ground with a standard wheel at 600 mm in the diameter) was used throughout the study. The wheels were fixed with three push-rims of different radii (46 cm, 50 cm, and 54 cm) and the rims had identical thickness and made of metal. The ground was made of linoleum on concrete. The subjects were allowed to practice a short period of time until they feel confident that they could handle wheelchair well prior to data collection.

Subjects were requested to propel the wheelchair while wearing a pair of latex gloves. The Novel® pressure sensors were adapted to collect hand pressures. Based on a previous study (Ramanathan et al. 2010), these sensors were validated with a good repeatability. The pressure sensors were inserted in the gloves and held in place by using a cotton bandage wrapped around the hand (Fig. 1). The pressure sensors were made as the sensor matrix with the thickness of 2 mm, each sensor taking an approximate area of 1.68–1.78 cm^2 and thus approximately 60 sensors involved in the measurement. The sampling speed, i.e. scanning all sensors per second, was 50 Hz. The five zones identified to assess the pressure distribution were the lower ulnar, the upper ulnar, the upper radial, the lower radial and the entire pressure map.

The Vicon® motion capture system was used to collect movement data. The Vicon® reflective markers were applied onto the trunk, shoulder and arms (Fig. 2) and the marker data were collected using 100 Hz. Twelve Vicon® MX13 digital cameras were arranged along a 25 m runway in the laboratory. When the subjects propelled the wheelchair through the runway at their selected speed, the motion capture system recorded marker positions during the propulsion. The researchers randomly arranged different sizes of push-rims for the subject for a trail and each subject did at least 5 valid trails for each size of push rims. Only the movement cycle in the centre capturing area rather than at the beginning and ending ones was further analysed, as wheelchair velocities were relatively stable there. The speed of wheelchair was calculated using the distance of the marker on wheelchair divided by the time taken in the cycle.

2.3. Kinematic model

Though there have been some models available (Debril et al., 2011; Faupin and Gorce, 2008; Kolwadkar et al., 2011; Kozey and Das, 2004; Wu et al., 2005), those models are not suitable for wheelchair situation where some markers on the back would be blocked by wheelchair back. Hence, a specially designed in-house model was developed to calculate the joint angles at the shoulder and elbow. This model consisted of three segments: the trunk, arm and forearm. Ten reflective markers of size 25 mm, nine on the subject were used to define the segments and one on the wheelchair to measure wheelchair speed. The anatomical position of the Vicon® reflective markers was determined according to the in-house designed model. Four markers were applied on the scapulothoracic segment, three on the arm segment and two on the forearm segment of the dominant upper-limb (Fig. 2). The definitions of three segments were shown in Appendix. These markers enabled us to calculate joint angles at the shoulder and elbow, and wheelchair speed. The reflective markers were applied using double-sided adhesive tape. The marker placement was done by the same researcher for all subjects. All kinematic data were calculated within a central cycle where the wheelchair propulsion had relatively stable speed.

2.4. Validation of the model

This model was validated using a specific multi-block prototype on which the markers were placed on the blocks for mimicking the human trunk and arm, and the angles between the blocks were measured manually using both a protractor and the model software simultaneously. Seventeen static trials were collected for the multi-block prototype, each trial being used to measure a defined angle between two blocks. The defined angles were from 0° to 85° with a 5° interval. Two sets of angles from manual measurement and the model software were statistically compared. The results showed that the linear correlation coefficient between the model and manual measured angles was 1.00; the mean of measurement differences between the two sets of angles was 0.14° (minimum −0.68 and maximum 0.94°); the standard deviation of measurement differences was 0.41°, confirming that the model was accurate in the calculation of joint angles (Fig. 3).

2.5. Phase definition and detection

The cycle of wheelchair propulsion was defined by meticulous analysis of the Vicon® data. This cycle consisted of two phases: the recovery and push phases. The cycle began with the recovery phase with maximum flexion at the shoulder joint accompanied by maximum extension at the elbow joint and finished with the push