A Descriptive Study on the Influence of Wheelchair Design and Movement Trajectory on the Upper Limbs' Joint Angles

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Abstract. Several aspects of the design and configuration of manual wheelchairs have been indicated as factors that influence the biomechanics of the upper limbs during manual propulsion. From a kinematic point of view, the angles of the shoulder and elbow are particularly important, as they can reveal potentially harmful joint positions as well as providing information that can complement the analysis of the performance of the propulsion technique. This study investigated the influence of two different designs of manual wheelchairs (rigid frame and foldable frame) on the shoulder and elbow angles during manual propulsion in straightforward and turning trajectories. Eleven subjects without disabilities performed a propulsion protocol comprising a 15-m straightforward sprint and a 2-m radius turn in both clockwise and anticlockwise direction. During the propulsion tests, data of shoulder and elbow angles were collected using accelerometers. The results revealed that manual propulsion with a rigid frame wheelchair may provide more protection as it was related to lower maximum angles of shoulder extension and abduction and elbow flexion-extension range of motion in comparison with the foldable frame chair. Providing a wheelchair design and configuration that reduces the biomechanical risks and increases efficiency may benefit the users' safety, independence and satisfaction with their wheelchairs.

Keywords: Wheelchairs · Biomechanics · Joint angles · Design · Assistive technologies

1 Introduction

Mobility is essential for most daily activities and is a factor influencing health status, social participation and quality of life. Recent data from WHO shows that more than 1 billion people have some form of disability, among which about 200 million have considerable functional problems [1]. In the US, at least 6.8 million people use assistive technologies and a quarter of those make use of manual wheelchairs for mobility [2].

F. Rebelo and M. Soares (eds.), *Advances in Ergonomics in Design*,
Advances in Intelligent Systems and Computing 588, DOI 10.1007/978-3-319-60582-1_64

A variety of physical disabilities limit the body movements in such a way that wheelchairs are needed. From an ergonomic perspective, the wheelchair must be considered not only as a mobility device, but also as a support interface, as the users occupy the chair for about 11 h per day [3]. Although widely used, the manual wheelchair has been related with various problems such as limited mobility, upper limb injuries and social participation [4–6]. Indeed, studies have shown that wheelchair users move slower and for lower distances than individuals without disabilities [3, 7–9].

Handrim wheelchair propulsion, the most common means of wheelchair mobility, has been considered a factor contributing to the high prevalence of upper limb injuries among manual wheelchair users. A study of Rice et al. [10] highlighted the high prevalence of carpal tunnel syndrome (from 49% to 73%) and shoulder pain (31% to 71%) in this population. The presence of pain is related to poor quality of life, being considered as one of the main reasons for the functional decline of the individual [11, 12]. Therefore, investigating how changes in wheelchair design and configuration can minimize the risks of developing injuries may benefit the safety and independence in manual wheelchair usage.

Providing a wheelchair that is suitable to the user's' characteristics, needs and preferences can benefit both mobility and satisfaction with the device. These are important ergonomic aspects influencing the successful use of assistive devices. In order to improve the ergonomics of manual wheelchairs, adjustments in the equipment configuration are important factors contributing to the wheelchair suitability. Biomechanically, small changes in users' relative position to the rear wheels can affect important aspects of the user-wheelchair interaction, such as: handrim propulsion forces, upper limbs range of motion (ROM), system stability and rolling resistance [4]. These are very relevant aspects of the ergonomics of manual wheelchair as, ultimately, they determine how easy or difficult it is to propel the wheelchair.

Adjustments in specific aspects of the wheelchair design, such as frame design, tires and the position of the rear wheels' axle, can influence the user's' actions during manual propulsion. The study of Louis and Gorce [13] shows the axle position affects muscle activation during manual propulsion. In addition, moving the axle forward has been related to an increase in the push angle [14], that is, the angle along the arc of the handrim from the initial contact to the release. Increased push angles may potentially benefit propulsion efficiency by reducing the push frequency. Additionally, a more forward position of the rear wheels has been associated with less muscle effort, and smoother joint excursions but, on the other hand, it affects rearward stability [15]. In this context, the investigation on how changes in wheelchair configuration influence users' actions during manual propulsion can provide ergonomic data for optimizing mobility efficiency and minimize the risk of upper limb injuries. This is an important knowledge for designers, manufacturers and the professionals who work with wheelchair design, prescription and provision.

Although there are many studies that evidence the influence of wheelchair design on different aspects of manual propulsion, it is, to the best of our knowledge still unclear how it influences the upper limb kinematics in different movement trajectories. This a relevant aspect, as the dynamics of a wheelchair in motion is dependent on the trajectory [16]. Therefore, the current study investigated the influence of wheelchair design on the shoulder and elbow angles during manual wheelchair propulsion in turning and straightforward trajectories.

2 Materials and Methods

Eleven subjects without disabilities were recruited at the São Paulo State University (UNESP, Bauru, Brazil) and voluntarily participated in the study. Participants met the following criteria: (1) 18 years or older; and (2) no history of upper limbs pain, injuries or disorders that could influence the manual wheelchair propulsion. Prior to data collection, volunteers were informed about the purpose and methods of the study, read and signed an informed consent form that had been submitted and approved by the Ethics Committee of the Faculty of Architecture, Arts and Communication - UNESP (Process. N. 800.500).

Two manual wheelchairs - one with a rigid frame (Starlite, ORTOBRAS) and one with foldable frame (AVD Alumínio Reclinável, ORTOBRAS) - were used. The wheelchair with rigid frame was used with the rear wheels' axle in the most forward position without affecting the stability of the chair, that is, 50 mm from the standard position (Fig. 1a). In turn, the wheelchair with foldable frame was used in its standard configuration, as it does not offer adjustments for the rear axle position (Fig. 1b).

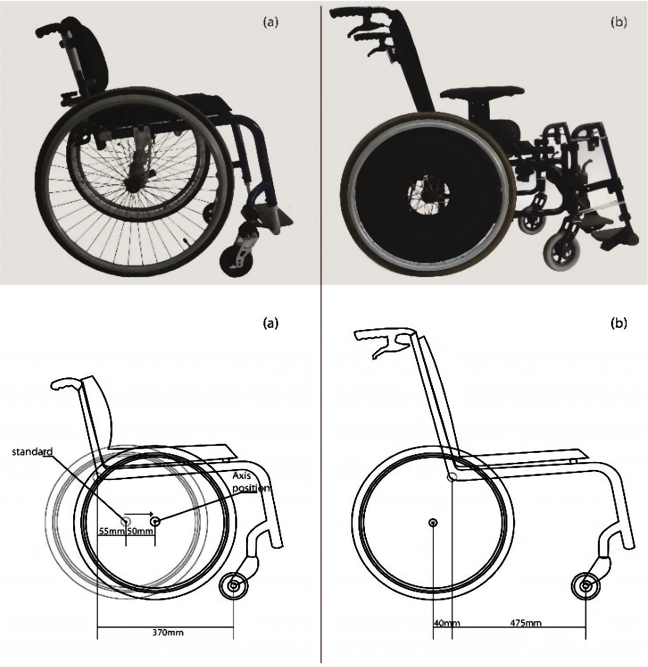

Fig. 1. Wheelchairs with frame and axle position: Rigid-frame wheelchair, total mass of 13 kg (a); Foldable-frame wheelchair, total mass of 17 kg (b).

The subjects were asked to propel the chair as fast as possible in three situations: 15-m straightforward sprint; 2-m radius turn in clockwise direction; 2-m radius turn in anti-clockwise direction. The tests were carried out on a flat asphalt surface and repeated twice: once with each of the two wheelchairs. The sequence of test for both the chairs and the trajectories were randomized.

During the propulsion protocol, kinematic data of shoulder and elbow angles were collected with a motion analysis system (CAPTIV System, TEA Ergo, Nance, France). Four motion sensors were positioned in the arm, forearm, pelvis and back, data was sampled at 2048 Hz, and the maximum angles of shoulder abduction, extension and flexion, as well as elbow extension and flexion were obtained with the CAPTIV L-7000 software (TEA Ergo, Nance, France). The measurements of all subjects for the maximum angles of shoulder and elbow were obtained, and presented descriptively using mean and standard deviation.

3 Results

Eleven subjects, all men, with an average age of 23.82 + 3.46 years, weight 76.09 + 11.43 kg and height 1.77 + 0.06 m participated in this study.

In general, the results showed that both the wheelchair design and movement trajectory are factors that influence the upper limbs' actions in terms of shoulder and elbow angles. For all the trajectories, propelling the foldable frame wheelchair was related to greater maximum angles of shoulder extension and abduction (−26.82 + 27.53°), and lower flexion-extension (flex/ext) range of motion of the elbow compared to the rigid frame wheelchair (Tables 1 and 2).

Table 1. Mean shoulder angles during manual wheelchair propulsion.

	Straightforward				Clockwise direction				Anti-clockwise direction			
	Abd	Flex	Ext	Fl/Ext	Abd	Flex	Ext	Fl/Ext	Abd	Flex	Ext	Fl/Ext
Fold. Frame	27.53	27.45	26.82	54.27	28.57	24.39	24.84	49.23	25.85	16.62	20.95	37.57
Rigid frame	26.89	39.35	17.84	57.19	24.59	36.29	11.97	48.26	22.38	30.69	10.21	40.90

Table 2. Mean elbow angles during manual wheelchair propulsion.

	Straightforward			Clockwise direction			Anti-clockwise direction		
	Flex	Ext	Flex/Ext	Flex	Ext	Flex/Ext	Flex	Ext	Flex/Ext
Fold. Frame	12.63	56.98	46.84	9.48	53.76	44.28	16.76	47.98	31.22
Rigid frame	7.50	59.93	50.02	8.51	52.82	44.32	18.06	53.31	35.25

Note: Flex: flexion; Ext: extension; Flex/Ext: flexion-extension range of motion

The analysis of the joint angles in terms of movement trajectory showed that, in general, the range of motion of shoulder flex/ext and abd/add were greater in the straightforward trajectory, and lower in the 2-m radius turn (counter-clockwise, that is, right upper limb in the inside of the curve). Additionally, the maximum angles of shoulder abduction and extension (both are critical for a safe propulsion) were also greater in the straightforward sprint and lower in the 2 m radius turn (Fig. 2).

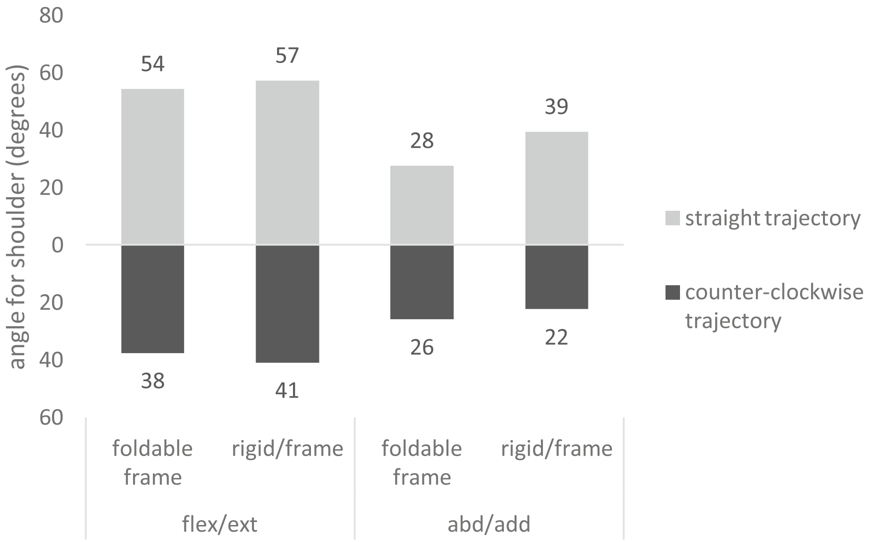

Fig. 2. Range of motion for shoulder joint angles.

4 Discussion

Wheelchair propulsion comprises the repetitive application of forces on the wheels. In the long-term, such combination exposes the users to an increased risk of upper limb injuries. In order to promote a safe and comfortable propulsion and minimize the risks, it is possible to select different designs of equipment as well as change the configuration of the wheelchair components. From a kinematic perspective, the most important factor affecting manual propulsion is the position of the wheels relative to the user. Therefore, this study addressed this equipment feature and how it influences the shoulder and elbow angles during wheelchair propulsion.

Manual propulsion with the foldable wheelchair was related to greater maximum angles of shoulder extension and abduction and lower ROM of flexion-extension elbow compared to the rigid frame wheelchair. Probable due to the most rearward position of the wheels, thus requiring the user a greater shoulder extension to reach back the handrim and, consequently, pushing the wheels in a smaller propulsion arc. Indeed, the rearward position of the rear wheels' axle has been related with a lower push angle and increased push frequency [14].

A large Contact Angle (the angle along the arc of the handrim, from contact to release) was observed in the foldable frame. That is recommended, as it has the potential to reduce the number of strokes needed to maintain a given speed. This results in a lower number of repetitive motions performed by the upper limbs. However, this condition increases the resultant force experienced at the shoulders during propulsion, which contributes to joint damage and injuries [17].

Although the current study provides important findings, it has limitations that need to be noted. First, only subjects without disabilities were observed, therefore the findings may not be fully representative of the wheelchairs users. Additionally, subjects perceived exertion was not assessed. This could clarify an important aspect of the user-device interface: whether these changes in wheelchair design and configuration are perceived or not by the subjects. Finally, as we decided to compare two of the most common designs of manual wheelchairs in Brazil in the original configurations, the position of the rear wheels' axle relative to the seat were not the same for both chairs. Future studies should focus on investigating the influence of the wheelchair characteristics separately.

5 Conclusion

This study showed that both wheelchair design and movement trajectory are factors that influence the shoulder and elbow angles during manual wheelchair propulsion. We found that a rigid-frame wheelchair, in the situations investigated, allowed propulsion technique that minimizes the upper limb angles that are important in the prevention of overload injuries. This is possibly due to the rear wheels' axle position, which is more forward than the foldable-frame wheelchair. Although there are other relevant differences (such as mass, weight distribution and equipment geometry), probably the axle position is the factor that most influence the kinematics of the upper limbs during manual wheelchair propulsion, as it determines the user's reach to the wheels. When it comes to mobility, manual wheelchairs should provide a balance between efficiency, stability and preservation of upper limbs function. In this context, the rigid frame wheelchair with an axle positioned in the most forward position may benefit the users as it is related to upper limb angles that are less harmful. This knowledge may contribute to the ergonomic design of manual wheelchairs that best meet the user's' needs and expectations, in order to improve overall mobility and social participation.

Acknowledgements. The authors gratefully acknowledge FAPESP (São Paulo Research Foundation, Grant Number 16/05026-6), CAPES (Coordination for the Improvement of Higher Level Personnel) and CNPq (National Council for Scientific and Technological Development, under Grant 458740/2013-6) for the financial support.

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