The Effect of Manual Wheelchair Design on Mobility: A Study with Non-Users and Experienced Wheelchair Users

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Abstract. The use of inappropriate wheelchairs is believed to limit mobility and reduce the freedom and quality of living for the user. This study therefore set out to investigate the influences of wheelchair design on the performance in a wheelchair agility test. Ten participants performed an agility test involving operating three manual wheelchairs with different designs as fast as possible. The wheelchair designs (independent variable) included a lightweight rigid frame, foldable frame and hospital model. The wheelchairs order was randomized for the agility tests. The time to complete an agility test (dependent variable) was measured with a chronometer. The results show that the use of the rigid frame wheelchair yielded the fastest performance during the agility tests, while the hospital model resulted in longer task-completion times. The findings support the view that active users should be provided with lightweight wheelchairs, as heavy hospital wheelchairs limit mobility.

Keywords: Wheelchairs · Field Tests · Equipment Design · Mobility

1 Introduction

According to data from the World Health Organization [1] 1 billion of people experience disability worldwide, of which about 1% need a wheelchair. In low-GDP countries, there are many challenges associated with providing people wheelchairs or, more specifically, the most appropriate wheelchairs. As result, user's mobility and satisfaction with the equipment are affected.

[*] Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames (first name then last name). This determines the structure of the names in the running heads and the author index. No academic titles or descriptions of academic positions should be included in the addresses. The affiliations should consist of the author's institution, town, and country.

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Manual propulsion, the main means of moving with a manual wheelchair, has been studied in terms of several biomechanical and physiological outcomes such as: cardiorespiratory and perceived exertion measurement [2-4], the activity of upper limbs muscles [5-6], upper limb kinematics [7-8] and hand surface pressure distribution [9]. From the users' point of view, the equipment weight is one of the main aspects considered when selecting and acquiring a wheelchair [10]. A variety of wheelchair configuration parameters can impact equipment mechanics, the dynamics of a wheelchair in motion and the biomechanical demand during manual propulsion [11]. The tire type, for example, is an important factor that must be considered in the equipment configuration: while solid tires have been claimed as requiring less maintenance, evidence has indicated that these tires increase rolling resistance [12]. In terms of equipment mechanics, wheelchair mass, dimension and mass distribution are important factors affecting the system inertia [13,14]. Additionally, it has been shown that the influence of the equipment mechanics on the movement dynamics and resistive losses are dependent on the maneuver and trajectory characteristics [15,16].

Data from the World Health Organization has shown that less than 5% of people who need to use a wheelchair in fact have an adequately adjusted wheelchair [1]. This is most common in low-GDP countries, where many users do not have access to a specialized prescription and provisioning of assistive technology (AT) systems and, as a result, they end up acquiring a wheelchair not matching their characteristics, needs and preferences. In Brazil, it is not uncommon to purchase a wheelchair oneself or have one donated if one is unable to acquire a wheelchair from a specialized rehabilitation center. Consequently, unsuitable wheelchair models are frequently used, such as hospital model wheelchairs intended for short distances or to be driven by a caregiver. Such models may be the only equipment available to the user, since these devices are commonly obtained through donations. However, the use of these devices without the correct prescription can directly influence the performance in daily mobility in addition to causing and aggravating postural problems and upper extremity fatigue, injury, or both. The wheelchair models were selected for this study based on such accounts given by many users and first-hand observations in clinical experience. This study investigated how the wheelchair design can influence the users' ability to move fast and agile on a standard agility test modified for wheelchairs.

2 Materials and Methods

A mixed experimental design was selected for this study with experience level as between groups factor and wheelchair type as a within groups factor. The between groups factor had two levels, namely experienced wheelchair users and novices. The within groups factor had three levels namely the rigid frame, foldable frame and hospital wheelchairs. Mobility performance in terms of task completion time was the dependent variable.

A total of ten male participants, aged between 22 and 43 years voluntarily participated in this study. Half of the participants had mean age of 30.8+7.9 years, a mean mass of 72.6+9.5 kg and mean height of 1.7+0.08 m. These participants were paraplegic due to spinal cord injuries and were active wheelchair users, recruited at SORRI BAURU Rehabilitation Center, with at least 2 years of experience with independent.

The other five participants (mean age 25+4.6 years, a mean mass of 75.2+5.7 kg and a mean height of 1.8+ 0.05 m) did not have any disabilities or experiences with wheelchair usage. Prior to data collection, the participants were informed about the objectives and procedures of the study, read and signed an informed consent form that had been approved by the Ethics Committee of the Faculty of Architecture, Arts and Communication – UNESP (Process. N. 800.500).

Three models of adult manual wheelchairs (Fig. 1) commonly seen in the Brazilian market were used in this study: a rigid-frame wheelchair (RFW) with a mass of 11.55 kg, built with tempered aeronautical aluminum alloy, pneumatic tires in the 24'' rear wheels and foam cushioned seat; a foldable-frame wheelchair (FFW) made of steel with a mass of 21 kg, with backrest tilt and leg/foot support adjustments, pneumatic tires in the 24'' rear wheels, and foam cushioned seat; and a hospital model wheelchair (HMW) with a mass of 15kg, frame made in iron, seat and backrest in fabric and solid tires in 24'' rear wheels.

Fig. 1. Manual wheelchair models (from left to right): rigid-frame wheelchair; foldable-frame wheelchair; hospital model wheelchair.

The mobility performance was evaluated with the modified agility test [17]. This test was selected for this study because it comprises straight and turn (to both sides) trajectories, acceleration and breaking (Fig. 2). A video camera and chronometer were used to document study data.

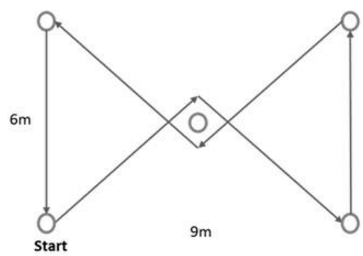

Fig. 2. *The Modified Agility Test for wheelchairs.*

Participants performed the agility test as fast as possible (repeated three times with each wheelchair type). The sequence of wheelchairs was randomized for all the participants and the time to complete the course was measured using a chronometer. Data is presented descriptively by means of mean and standard deviation (SD). The measurements were transformed using the Aligned Rank Transform (ART). The Aligned

Rank Transform is a non-parametric procedure that allows measurements that do not meet the assumptions of parametric tests to be analyzed using traditional repeated measures ANOVA. Post-hoc testing was performed using Bonferroni corrections. Statistical analyses were conducted using JASP version 0.9.1.0 [18] and ArtTool [19].

3 Results

The measurements satisfied the assumptions of sphericity. However, Levene's test revealed that the hospital wheelchair data did not satisfy the assumption of equality of variances ($F(1, 8) = 8.562$, $p = .019$). The data was therefore subjected to the aligned rank transform. A repeated measures ANOVA revealed a significant effect of device type ($F(2, 16) = 9.29$, $p = .002$), but not of participants' experience ($F(1, 8) = 3.95$, $p = .082$), with no interaction between these two factors ($F(2, 16) = 0.73$, $p = .498$). Post hot tests with Bonferroni correction show that the performance in the agility test with the hospital wheelchair was significantly different to both rigid ($p = .005$) and foldable (p = .03) chairs, while the results of the agility test with the foldable and rigid were not statistically different to each other ($p = .45$). Fig. 3 shows the performance of users and non-users in the agility test with the three wheelchairs.

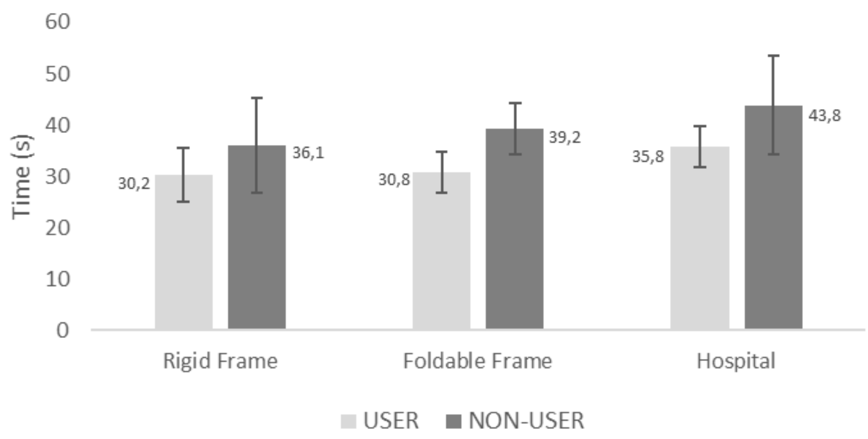

Fig. 3. Time of users and non-users in the agility test with the three wheelchair designs.

4 Discussion

Although it may seem obvious that RFWs allow the fastest performance in comparison to HMWs and FFWs, the magnitude of the time differences in a simple, rapid and controlled test of agility in manual wheelchairs allows to estimate the extent to which the design of manual wheelchairs can affect basic maneuvers in daily mobility. The current findings indicate that the use of the HMW resulted in increased time to complete the agility test in comparison to the other wheelchair models. The equipment configuration and the use of solid tires are probably two factors that contributed to this result. The study of Kwarciak et al. [12] showed that solid tires increase wheels' rolling resistance.

The findings support the claims that users should be provided with a lightweight wheelchair, as well as the risk of mobility limitation that the user might be exposed when using heavy manual wheelchairs or with configuration and accessories that do not target optimal performance. A previous study reported benefits of lighter wheelchairs [20]. In this context, designers, engineers, rehabilitators and other professionals may benefit from the information presented herein. However, this study has limitations that should be noted. The small sample size and the fact that half of the participants' sample being participants without disabilities and with no experience in manual wheelchair usage may limit power of the current findings, which, thus, may be not fully representative of the wheelchair user population. Future studies should address these issues, as well as measuring inertial properties of the different wheelchair designs so that it can be correlated with the data from the participants. Also, from the perspective of the users' efforts, measuring physiological parameters such as oxygen consumption may provide objective data in terms of energy costs for the users when moving with manual wheelchairs of different designs.

5 Conclusion

This study addressed how the use of different designs of manual wheelchair influence the performance in an agility test. The results indicate that lightweight rigid frame wheelchairs are more efficient, while hospital model wheelchair with solid tires demand more time to complete the course trajectory, therefore affecting the mobility performance negatively. The results support the view that specialized prescriptions provide the most appropriate wheelchair for the user.

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