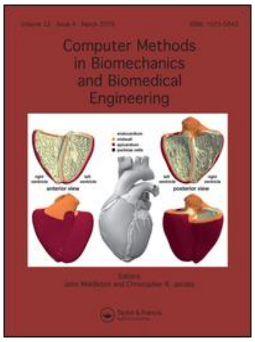

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Assessment of power losses due to ground contact forces during usual manual wheelchair movements

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KEYWORDS Manual wheelchair; movement resistances; rolling; turning

1. Introduction

Manual wheelchair (MWC) allows disabled people to recover autonomy, but may overload their upper limbs, causing pain or musculoskeletal disorders (Mercer et al. 2006). The stresses sustained by the MWC user are due to the muscular forces necessary to execute useful MWC movements (accelerating in straight line or in rotation, keeping up the velocity, climbing up a ramp …). Unfortunately, a non-negligible part of these efforts is wasted in useless movement resistances (Lin et al. 2015). Thus, lowering these resistances, mainly due to ground/wheel contact, would favour the decrease of the constrains sustained by the user upper limbs. Many studies focused on assessing these resistances for straightforward propulsion of the MWC, but very few addressed the quantification of the energy lost during turning manoeuvers (Lin et al. 2015). Recently, our team quantified the values of wheel swivelling resistance torque, which depends on the wheel type, ground nature, load applied on the wheel and the curvature radius of the wheel trajectory (Fallot et al. under review). Based on these values, the aim of the present study was to quantify the energy lost during typical daily living activities with a MWC.

2. Methods

2.1. Subjects and test protocol

Eight healthy subjects propelled an instrumented MWC (FRET 2), equipped with 6-components dynamometers on both handrims and on the chassis, rear wheel angular potentiometers and an inertial measurement unit (Sauret et al. 2012) during 5 min blocks of level-ground displacement (covered with low-pile carpet), performed at self-selected speed. Two measurement sessions of three blocks were performed by all subjects. Each block consisted in a guided succession of start-ups, propulsions in straight line, slaloms, stops, and half turns.

2.2. Data gathering and analysis

Using the instrumented MWC, the user efforts on both handrim, the seat, the backrest and the footrest, as well as the MWC kinematics could be measured. Vertical ground reaction forces on front and rear wheels were assessed as described in (Sauret et al. 2013). Each wheel kinematics were also assessed. The mass and center of mass fore-aft position of the instrumented MWC was previoulsy determined using force plateforms.

By considering each wheel type and radius, its rolling resistance factor could be assessed (Sauret et al. 2012). By considering each wheel type and MWC instantaneous center of rotation (ICR), its swivelling resistance factor could be determined. Multiplying rolling and swivelling resistance factors by the load applied on each wheel gave the rolling and swivelling resistances torques. By multiplying these torques by each wheel angular velocity, the power losses could be computed. Time integration of the power losses provided the energy spent during each activity.

MWC movements were classified in straightforward propulsion (linear velocity superior to 0.02 m/s and rotation velocity inferior to 0.2 rad/s), and turning motion (rotation velocity superior to 0.2 rad/s).

The mean power lost in rolling and swivelling resistances, for each wheel and in each movement classification, were then compared.

3. Results and discussion

The instrumented MWC mass was 38.2 kg and its centre of mass fore-aft position was 10.9 cm from the rear axle. 100 N load applied on front or rear wheels induced rolling resistance torques of 3.5 and 1.5 Nm respectively. Furthermore, considering in addition a 0.4 m gyration radius for the wheel trajectory, front and rear wheel swivelling resistance torques were 0.91 and 0.084 Nm respectively.

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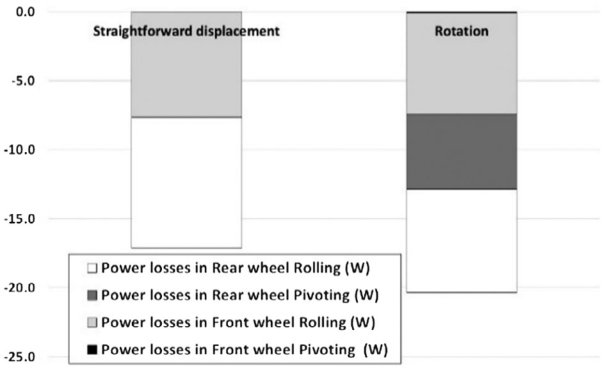

Figure 1. Mean power of rolling and swivelling resistances, for each movement and wheel types.

Averaged ground reaction forces on front / rear wheels (all subjects and trials mixed up) were respectively 281 N/817 N for straightforward movement and 291 N/797 N for rotation. These values were similar for both movements and could be explained by the choice of comfortable self-selected speed which imposed few trunk movements resulting in few weight transfers on front wheels. The larger weight applied on front wheels during rotation movement could be explained by the bending of the trunk during this movement. The total time spent in linear movements (275 s, summing all trial and subject durations) and to the one spent in rotation manoeuvers (218 s) were similar.

The mean of linear velocities performed were 0.70 m/s for straightforward movement and 0.78 m/s for rotation movements, which means that most of the rotation movements were not 'on-the-spot' rotations. Mean angular velocity was 0.18 rad/s (10°/s) for rotation movements. These values were inferior to the velocity usually observed during straightforward propulsion as start-up phases were considered in the movements, where initial velocity was near to zero.

Mean power losses during straightforward movement were 7.6 W by front wheels and 9.4 W by rear wheels. Indeed, the rear wheel rolling factor was lower than the front wheel one but higher load was applied on rear wheels, increasing the power they dispelled (Sauret et al. 2012).

Concerning MWC rotation manoeuvers, the mean of power losses due to wheel swivelling resistance were 0.1 W for front wheels and 4.3 W for rear wheels. These results were not surprising considering that the front wheel swivelling resistance parameter was far lower than the rear wheel one and that the load applied on front wheels was also lower than the one applied on rear wheels. During turning manoeuvers, power losses due to rolling resistance in front and rear wheels were respectively 5.8 and 6 W, which is comparable to power losses in wheel swivelling.

Swivelling resistance proved to be non-negligible with respect to rolling resistance and should be considered when quantifying the energetic performance of a MWC. Whereas rolling resistance power losses proved to be similarly distributed between front and rear wheels, high discrepancies were found between wheels during MWC rotation. This prevalent effect of rear wheel in rotation movement could be interesting when setting up a MWC, as front wheels could be chosen only considering rolling resistance performance. As rear wheels induce energy losses in both manoeuver types, their rolling and swivelling performances should be considered.

Healthy subject movements certainly differed from those of MWC experts, but for comfortable speed, the effect of this difference on front and rear ground reaction force and speed may not be enough to alter significantly the conclusions of this study.

Computing the mean energy spent in 1 min trial in rolling and swivelling resistances, which could be roughly compared to 1 min of daily life activity, showed that the user had to produce 1112 J to overcome the main MWC movement resistances.

4. Conclusions

The knowledge individual wheel contact forces between MWC and ground was used to assess power losses in any situation. It also opens the path to realistic simulation of MWC propulsion, not limited to straightforward movements. Power losses in MWC turning motion proved to be non-negligible: as they may often occur during daily living (propulsion in an apartment, sports …), they should be addressed when trying to adapt the MWC settings to the user environment.

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