Measurement of wheelchair adjustment effects on turning deceleration

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1. Introduction

Manual wheelchair (MWC) locomotion combines straightforward and turning motions, in everyday life as well as in sport practice. Many authors demonstrated the effects of various MWC properties, such as geometry or wheel type, for straightforward displacements (Brubaker 1986; Medola et al. 2014), while only few studies have investigated their influence for turning motion (Bascou et al. 2014; Caspall et al. 2013; Kauzlarich, Bruning, and Thacker 1984). In particular, the impact of wheelchair setup on its turning deceleration, which characterizes the MWC tendency to stop its turning motion, is unclear. This study aims at clarifying the effects of MWC adjustments on turning deceleration in the field, using a fractional factorial design.

2. Methods

2.1 Materials

An inertial measurement unit (MTi, X-sens, The Netherlands) was placed on the frame of a sport MWC whose front wheels were removed and replaced by a custom fork device (Figure 1).

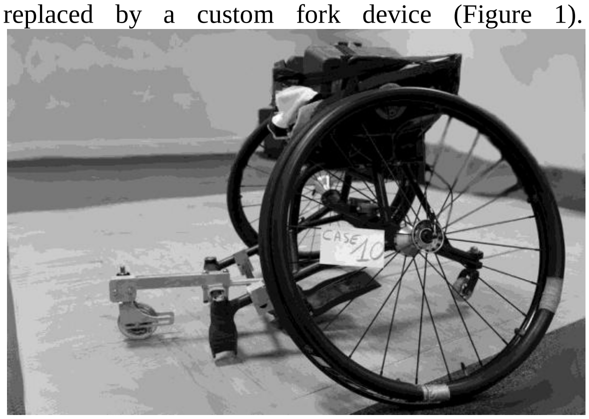

Figure 1: MWC, custom fork and additional masses

The MWC was loaded with 40 kg of additional mass, fixed on the seat. The fore-aft location of the additional mass and the custom fork allowed changing the fore-aft location of the total centre of mass (COM) with respect to the rear wheel axle (factor "A", ranging from 0.04m to 0.07m), the inclination of the fork hinge (factor "B, ranging from 0° to +3°), the fork trail distance (factor "C", ranging from 0.03m to 0.08m), the caster wheel diameter (factor "D", ranging from 0.06m to 0.08m) and the location of the fork hinge with respect to the rear wheel axle (factor "E", ranging from 0.50 m to 0.63m).

2.2 Fractional factorial design

8 sets of 5 turning deceleration tests were performed to define the influence of the MWC setup on its turning behaviour. In each trial an experimenter initiated the MWC rotation in clockwise direction and let the MWC turning freely during about 1 second. For each set, the 5 previously described MWC parameters (factors A to E) where changed according to a fractional factorial design (Taguchi 1987) with 2 levels (Table 1). The factorial design experiments provided a model allowing the assessment of the MWC angular deceleration according to its settings:

$$\dot{w} = a_0 + a_A l_A + a_B l_B + a_C l_C + a_D l_D + a_E l_E + a_{AB} l_A l_B + a_{AD} l_A l_D$$

where $\dot{w}$ is the MWC angular deceleration, l_A, l_B, l_C, l_D, l_E, are the level values (between +1 and -1) for the parameters A to E, and a_A, a_B, a_C, a_D, a_E their respective effects. Second and third order interactions between factors were neglected, except for interactions AB and AD (with effects a_{AB}, and a_{AD}).

In order to evaluate the impact of possible ground inclination, set 1 was repeated (set 1b) in counter-clockwise direction. Two additional sets (sets 10 and 11) were performed for model verification.

Trial/ factor	A	B	C	D	E	AD	AB	Angular deceleration rad/s²(±SD)
1	-1	-1	-1	-1	1	1	-1	2,8 (±0,4)
2	-1	-1	1	1	-1	-1	-1	1,8 (±0,1)
3	-1	1	-1	1	1	-1	1	2,1 (±0,1)
4	-1	1	1	-1	-1	1	1	3,0 (±0,2)
5	1	-1	-1	1	-1	1	-1	3,8 (±0,3)
6	1	-1	1	-1	1	-1	-1	4,2 (±0,3)
7	1	1	-1	-1	-1	-1	1	4,2 (±0,3)
8	1	1	1	1	1	1	1	4,0 (±0,1)
1b	-1	-1	-1	-1	1	NA	NA	2,5 (±0,2)
10	1	-1	1	1	1	NA	NA	3,6 (±0,2)
11	1	1	1	1	1	NA	NA	4,1 (±0,2)

Table 1 MWC settings during experimental plan and resulting angular deceleration

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2.3 Data treatment and hypothesis

The MWC angular velocity was computed assuming a planar movement: the rotation velocity was the resultant of the angular velocity measured by the Inertial Measurement Unit. The angular deceleration was obtained by time differentiating the MWC angular velocity.

3. Results and discussion

During the free turning phase, the MWC angular deceleration was constant (for every selected trials, the angular velocity followed a decreasing line with a correlation coefficient r² superior to 0.98), which supports the hypothesis that deceleration was not linked to MWC angular rotation velocity during the free turning phase and was directly linked to MWC settings.

Mean deceleration value a_0 was 3.2 rad/s^2. Main effects were attributed to the fore-aft location of the total COM and the diameter of the front casters (Figure 2). The effect of fork angle and fore-aft position was significant, but represented less than one fourth of the caster diameter and on tenth of the total COM position. The fork trail had a very low effect in this movement as the rotation was already initiated, but should have an effect in the rotation initiation.

The total COM position had a high effect as it changed both the total inertia and load distribution on the front and rear wheels, which is in accordance with previous theoretical results (Bascou et al. 2014). The user can have a direct action on this parameter by modifying his posture, leaning forward to decrease (/ backward to increase) the rotation.

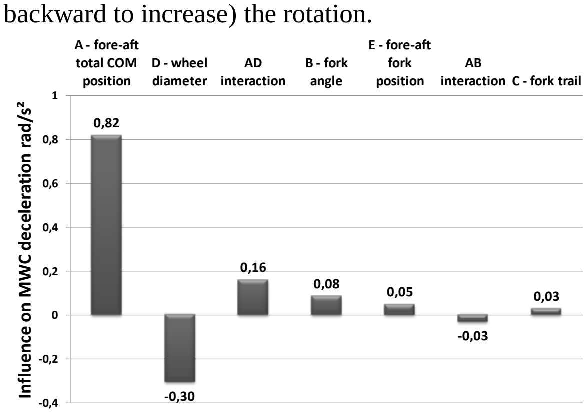

Figure 2 Effects of MWC settings on its deceleration

The wheel diameter also had a significant effect, possibly due to a variation of rolling (linked to the wheel radius) and swiveling resistances. This assumption is supported by the non negligible value of interaction between total COM position and the front wheel diameter (interaction AD).

Turning the MWC in counter-clockwise direction (trial 1b) resulted in a 8% difference with respect to the clockwise direction (trial 1), potentially due to a slight ground inclination. Comparing the model results with the experimental ones (sets 10 and 11) resulted in 8% and 7% errors respectively, which is acceptable considering a fractional factorial design model.

The hypothesis of negligible effects of AC and AE interactions was validated *a posteriori* considering the low effects that were observed for factors C and E.

4. Conclusions

This study allowed the experimental classification of the effects of various MWC settings on its angular deceleration in the field. The results underlie the importance of total COM position and the choice of front caster diameter. Further work should be conducted, particularly to assess the wheel swivelling resistance contribution to the MWC manoeuvrability and to cancel the effect of ground inclination.

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