A preliminary investigation of handrim kinetics in various environmental situations crossed in manual wheelchair

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1. Introduction

During manual wheelchair (MWC) locomotion, the user's upper limbs are subject to significant levels of stress and fatigue because the upper body is permanently engaged to propel the MWC and in all daily activities (van der Woude et al. 2001). This stress can lead to pain and wounds in the upper limbs which in turn may lead to difficulties in autonomy and social integration for MWC users.

Suggesting adequate and accessible paths for urban locomotion to MWC users could be a way to reduce the loads sustained by the upper limbs for this population. Tools for suggesting accessible places have already been forwarded in several smartphone applications, but no solution is currently able to provide the best accessible path to move from one place to another. This primarily requires the definition of a quantitative criterion that can be linked to the user' individual physical capacities

In the literature, the physical difficulty of a situation is generally described using either the propelling torque (i.e. the torque acting at the wheel hub and that ensure the wheel rotation) or through the total force applied by the user on the handrim (Koontz et al. 2005; Richter et al. 2007). However, it is unknown if the ranking of the situation difficulty based on these two criteria are equivalent.

Hence, the aim of this preliminary study was to evaluate the ranking of various environmental situations according to the two previous criteria: propelling torque and the handrim total force.

2. Material and methods

2.1. Experimental data

One young male able-bodied subject participated in this preliminary study. He was asked to cross different situations using an instrumented MWC (FRET-2) equipped with right and left instrumented wheels allowing the measurement of forces and torques applied by the user on both handrims (Sauret et al. 2011).

The studied situations were: start-up, clockwise U-turns, slopes inclined at 5 % and 12 % (7 m long), left cross-slope inclined at 10% (6 m long), and mounting 20 mm and 45 mm kerbs. Five trials were performed for each situation excepted for the slope 12 % where two trials were performed. For slopes and cross-slope, the participant was pushed by an assistant during the first cycle to facilitate reaching a steady-state velocity. Only the first and second cycles were considered for start-up and only the second to the fourth cycles were considered for slopes and cross-slope. For kerb ascent, the MWC was initially resting with the front wheels on the elevated surface and the task was performed without any initial velocity.

2.2. Data processing

Maximums of absolute values of the propelling torque and of the handrim total force were extracted for each cycle and task and for right and left handrims. Mean values of these maxima for each situation were then used to rank the different situations.

3. Results and discussion

Results based on total force are presented on Figure 1. For both handrims, the 12% slope and 45 mm kerb required the highest levels of total force. Then, there is a group of situations requiring moderate level (compared to other situations) of total force on both handrims: 5% slope, 20 mm kerb, and U-turn.

Based on the total force criterion, start-up was found slightly less constraining than the other investigated situations. Finally, the cross-slope was the most interesting situation because it required small levels of forces on the right handrim but was found among the highest constraining tasks on the left handrim. In the case of the cross-slope and the U-turn, both handrims must be considered to rank the situations.

Propelling torques used as a criterion results in different observations (Figure 2). The 12% slope and 45 mm kerb were also found the most constraining but they were followed by 20 mm kerb for both handrims. The 5% slope and U-turn were ranked just after. Start-up was also found among the less constraining tasks among the studied situations for both handrims. Based on propelling torque, cross-slope was also ranked among the less constraining tasks for both handrims, while it was found among the most constraining tasks based on the right handrim total force. This low propelling torque associated to a high

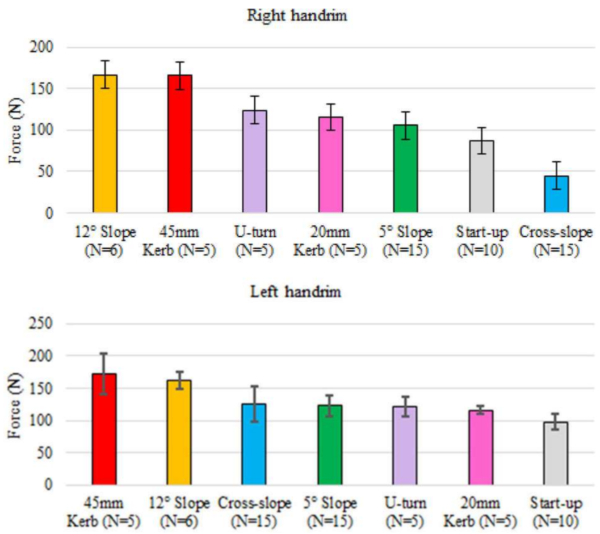

Figure 1. Ranking of the situations based on peak values of right and left handrim total force during propulsion.

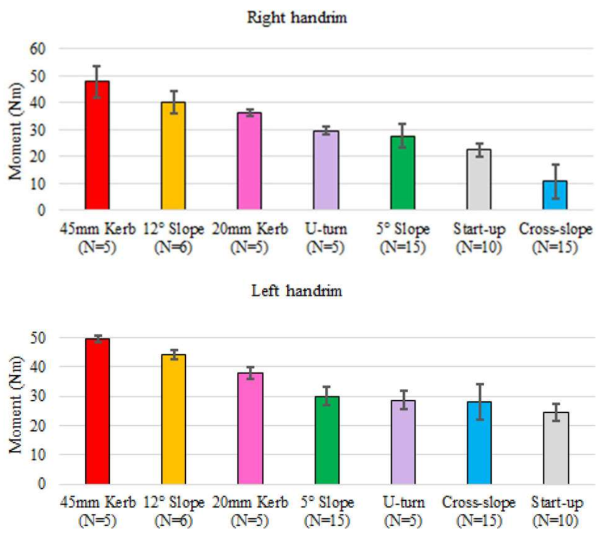

Figure 2. Ranking of the situations based on peak values of right and left propulsive moments during propulsion.

handrim total force can be seen as a loss of mechanical efficiency because a larger part of the force applied on the handrim did not allow creating a propelling torque (that ensure the wheel rotation). Indeed, in this specific situation, the analysis of the 3D-compoments of the force shows higher fore-aft component than in other situations. This apparent non-useful part of the total force mechanically creates, by reaction, a fore-aft force on the seat that creates a yaw torque at the downstream side wheel contact point with the ground that counterbalances the tendency of the MWC to turn and roll downhill. As a consequence, the propelling torque criterion underestimates the difficulty of the cross-slope situation.

Hence, comparing the results obtained from handrim total force and from propelling torques, which are both handrim kinetics variables, showed differences in the analysis of the constraints related to the different environmental situation.

4. Conclusions

Involving only one subject, this study remains preliminary. However, this study provides first results on total force and propelling torques during a wide range of situations. In particular, this study mainly demonstrates that ranking the situation strongly depends on the selected criterion, even when using two close parameters such as handrim total force and propelling torque. This study also showed the importance of measuring the forces and torques on both handrims.

In this sample of situations, the total force could be seen as more appropriate than the propelling torque but other parameters could also be relevant such as the impulse or the shoulder net joint moment, for instance; and these other parameters may also lead to different rankings. So, it appears that further research is still needed to quantify the physical difficulty of different environmental situations crossed during MWC locomotion. It is planned to carry out this study with a larger cohort of subjects. Also, quantifying the difficulty of an environmental situation might not be based on a single parameter but rather on a combination of several parameters and might be subject to the user's physiology and experience.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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