The effect of force direction at the pushrim on joint moments in the upper extremities during manual wheelchair propulsion

Guillaume Desroches [1,2], Rachid Aissaoui [1,2,3], Daniel Bourbonnais [3], Christian Y. Perron[1]

[1] École de technologie supérieure (ÉTS), Montréal, Québec
[2] Laboratoire de recherche en imagerie et orthopédie (LIO), Montréal, Québec
[3] C.R.I.R., Site Institut de réadaptation de Montréal (IRM), Montréal, Québec

Guillaume Desroches : guillaume.desroches.1@ens.etsmtl.ca

Abstract

The purpose of this study is to evaluate the relationship between the resulting force direction and the load sustained by the shoulder during manual wheelchair propulsion. Fourteen elderly subjects (66-77 years) have been tested and the joint moments were computed using 3D generic inverse dynamic software. The direction of the pushrim force determined the maximal distance between its projection and the shoulder location (Dmax). The greater the distance, the more tangential is the force and therefore physiologically costly. A correlation analysis showed a significant positive relation of Dmax with the shoulder flexion moment (r = 0.54, p < 0.001) and also with the shoulder adduction moment (r = 0.35, p<0.001). The analyses also showed a significant but negative correlation between Dmax and the shoulder abduction moment (r = -0.30, p<0.001). Our results suggest that shoulder joint moments tend to be higher when the resulting pushrim force is oriented according to the tangential direction. Consequently, the physiological cost would be higher for those users.

1. INTRODUCTION

For people with diminish mobility, a manual wheelchair (MWC) can be a valuable device to regain autonomy in their daily life activities. However, as shown in some studies [1, 2], the incidence of shoulder pain ranges between 31 and 73 % for frequent users of MWC. More specifically around the shoulder area, the most common injuries are the impingement syndrome and rotator cuff tears [2]. These lesions can partially be explained by the high loads that MWC propulsion brings to the anatomical structures of the upper limbs [3]. Veeger *et al.* [4] established that the rotator cuff muscles reach 30 % of their maximal isometric activity during the propulsion phase. These muscles, due to their smaller volume, are more subject to fatigue during a repetitive task [5], and even more in an elderly population where the baseline strength is considerably lower than young adults [6]. Therefore, if the muscles cannot accomplish their main function (stabilize the glenohumeral joint) because of the high load and repetitive task, it could lead to shoulder injuries.

A useful method to quantify the load on the shoulder is by the calculation of joint moments during MWC propulsion [7]. In an experiment conducted on 16 SCI patients, Sabick *et al.* [3] reported that the shoulder flexor and adductor muscles are those which sustained the highest load (> 20Nm) during the propulsive phase, an observation confirmed by the results from other studies [4, 8]. Veeger *et al* [4] stated that these loads were dependent upon the propulsion technique and the resulting force direction. In another study, Rozendaal *et al* [9] hypothesized that the direction of the resulting force is a balance between the cost and the efficacy of the propulsion. They defined a zone, according to the minimum effort theory, in which the direction of the force is optimal relative to the mechanical cost at the joints. However, in their analysis, the authors [9] did not examine the load on the upper extremities.

A simple way to represent the pushrim force direction is to compute the distance (D) between the projection of the resulting force and the shoulder location. It gives an appreciation of how close the force is from the effective direction (tangential) [9]. Thus, we hypothesized that a manual wheelchair user who produces a force close to the tangential direction (high Dmax) would undertake greater mechanical load on the shoulder. Therefore, the main objective of this paper is to determine if there is a relationship between the force direction (D) at the handrim level and joint moments at shoulder.

2. METHODS

2.1 Subjects and protocol

The experiment was done on 15 elderly subjects (66 to 77 years old) who were frequent users of a MWC. The experimental protocol can be found in an earlier paper [10].

2.2 Joint moments

The joint moments were obtained using a 3D generic inverse dynamic as described by Dumas *et al.* [11]. The moments were expressed according to the local coordinate system defined by Cooper *et al.* [12] and were normalized across the propulsive cycle. The joint moments obtained from the inverse dynamic were those of adduction/abduction, internal/external rotation, flexion/extension in the sagital plane and flexion/extension in the horizontal plane. The maximum value of each parameter was computed for each moment for every propulsion cycle.

2.3 Force direction

In theory, the mechanically optimal pushrim force direction around the wheel is the tangential one. However, this direction has been proven to be physiologically costly and therefore not optimal for wheelchair propulsion [9]. The force direction here is expressed as the distance (D) between the projection of the resulting force and the shoulder marker (fig.1). The greater the distance is, the closer the force is to the tangential direction. The maximum distance (Dmax) was assessed for each propulsion cycle.

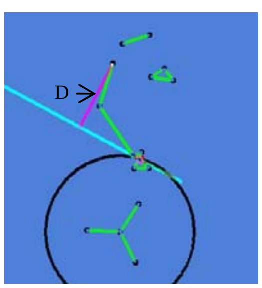

Figure 1: Graphical representation of the distance between the projection of the resulting force (blue) and the shoulder (yellow marker)

2.4 Data analysis

All analyses were carried out using Statistica software (StatSoft, Inc.). The Pearson r correlation coefficient was computed to see if there was any relationship between the force directions (Dmax) and the joint moments calculated. All significance levels were set at $p < .05$.

3. RESULTS

According to our results, Dmax showed a small but significant positive correlation with the maximal external rotation moments ($r = 0.15$, $p = 0.021$) (Fig.2a). However, a low negative correlation was found between Dmax and maximal internal rotation moment ($r = -0.068$, $p=0.336$) (Fig.2a).

In the frontal plane, Dmax showed a significant negative correlation for abductor moments ($r = -0.30$, $p<0.001$) (Fig.2b) and a positive correlation for the adductor moments ($r = 0.35$, $p<0.001$) (Fig.2b).

The correlation analysis of the flexor/extensor moments in the sagittal plane showed significant positive correlation for the flexor moments ($r = 0.54$, $p < 0.001$) and negative correlation for the extensor moment ($r = -0.13$, $p = 0.04$) (Fig.2c).

The analyses did not reveal any significant correlation for the flexor/extensor moment in the horizontal plane.

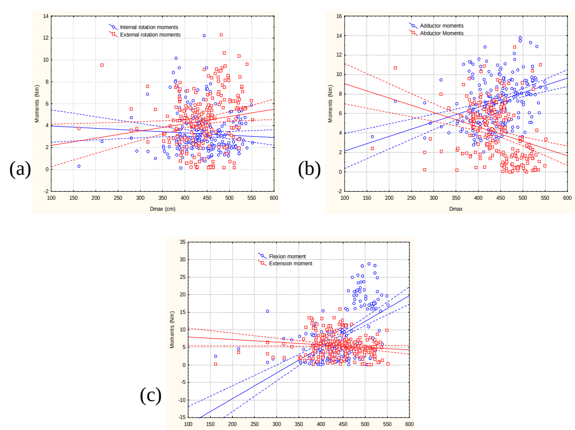

Figure 2: (a) scatter plots of internal (blue)/external (red) rotation moments by Dmax. (b) scatter plots of adduction (blue)/abduction (red) moments by Dmax.; (c) scatter plots of flexor (blue)/extensor (red) moments in the sagital plane by Dmax. The correlation line is displayed for each moment.

4. DISCUSSION AND CONCLUSIONS

Our analyses show that the distance between the projection of the resulting force and the shoulder influences the load sustained by the shoulder. More precisely for the flexor and adductor moment, our results suggest that the more the force is directed tangentially (greater

Dmax), the greater is the moment around the shoulder and therefore the physiological cost of propulsion.

The next step would be to investigate whether some parameters may influence the force direction over the course of propulsion toward a more optimal one. As suggested by Veeger *et al.* [4], the propulsion technique could influence the force production and, therefore, the direction of the latter. A reduction of Dmax (less oriented in the tangential direction) would yield lower load on the shoulder and could diminish the risk of overuse injuries on the shoulder. Future works will concentrate on this particular idea.

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