

DRAG FORCE NORMALIZED WHEELCHAIR PROPULSION FORCES

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INTRODUCTION

Ground reaction forces are commonly normalized by subject body weight in gait biomechanics studies. This method of normalizing is justified since the reaction forces are directly related to body weight. Handrim forces are used instead of ground reaction forces when studying wheelchair propulsion biomechanics. Just as in gait studies, it is desirable to normalize the resulting handrim forces to allow users of varying weights to be compared. However, it is the wheelchair wheels, not the handrim forces that support the user's body weight when using a wheelchair. While an association has been found between a user's body weight and the magnitude of peak forces on the handrim for level propulsion (Boninger, 2000), it is likely that this relationship is driven by secondary factors such as the propulsion technique of the heavier population. This pilot study investigates an alternative normalizing value, the effective drag force (EDF), for use in propulsion studies. The EDF represents the minimum handrim force required to maintain forward propulsion for any particular user on any particular propulsion environment.

METHODS

A single full-time manual wheelchair user was recruited to participate in the study. The subject's rear wheels were replaced by propulsimeter instrumented test wheels, which measure the 3D forces and moments applied to the handrim during propulsion. The subject sat in his wheelchair, with his hands in his lap, and the wheelchair tethered to the front of a research treadmill

(Figure 1). The tether was instrumented with a load cell to measure the drag force.

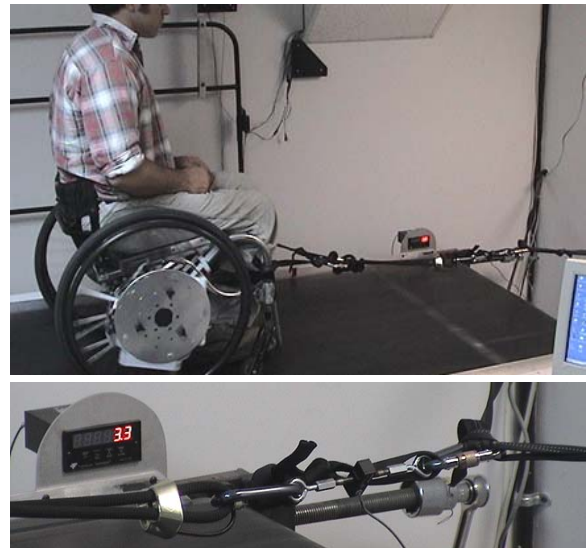


Figure 1: The experimental setup included a load cell instrumented tether to measure the drag force. Handrim forces were measured using a propulsimeter instrumented wheel.

Drag force was measured for treadmill speeds of 0.45 and 1.34 m/s on grades of 0, 3, 6, and 9 degrees. The effective weight of the subject was then increased, by adding 11.3 kg (25 lb) of mass under the seat, and the drag force was re-measured for each of the treadmill speeds and grades.

The subject was then asked to propel at a self-selected speed on each of the treadmill grades for 20 pushes while handrim forces were measured. The subject then repeated the process with the additional mass under his seat. The peak forces for the 20 pushes were averaged for each of the experimental conditions. The average peak forces were normalized by the subject's body weight (bw) and by the effective drag force (EDF). The EDF was calculated according to equation (1), using $\frac{1}{2}$ the measured drag

force (DF), since for straight propulsion, handrim forces from only one side of the wheelchair are required due to symmetry. D_w and D_{hr} were the diameters of the wheel and handrim respectively.

$$EDF = \frac{1}{2} DF (D_w/D_{hr}) \quad (1)$$

RESULTS AND DISCUSSION

The resulting drag force for each of the speed, grade, and weight combinations are given in Figure 2. Drag force was not affected by treadmill speed. On the level surface, drag force was not substantially affected by the additional weight. However, as the grade was increased, the drag force increased proportionally to the sine of the treadmill grade.

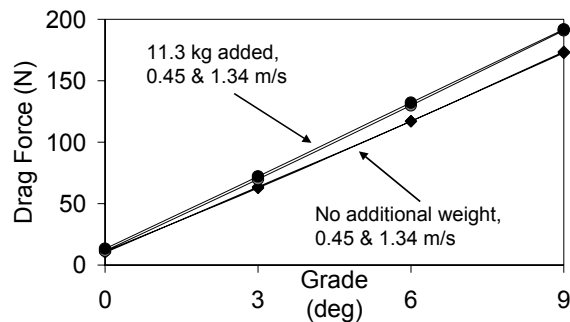


Figure 2: Drag force for varying speed, grade, and weight conditions.

The resulting peak handrim forces for the subject and the weight-added subject are shown in Figure 3 (top). The self-selected speeds for the increasing grades were: 1.48, 0.85, 0.58, and 0.49 m/s. As expected, the handrim forces increased for propulsion on increasing grades. The body weight normalized forces are simply scaled versions of the un-normalized forces. The body weight normalized scale is given on the right.

The EDF normalized forces for the subject and weight-added subject are given in Figure 3 (bottom). The EDF normalized forces exhibited a unique and insightful relationship with treadmill grade. As grade

increased, the normalized forces decreased, approaching but never reaching the 1.0 physical limit. As was expected, the results were very similar between the subject and weight-added subject trials, demonstrating the effectiveness of EDF normalizing.

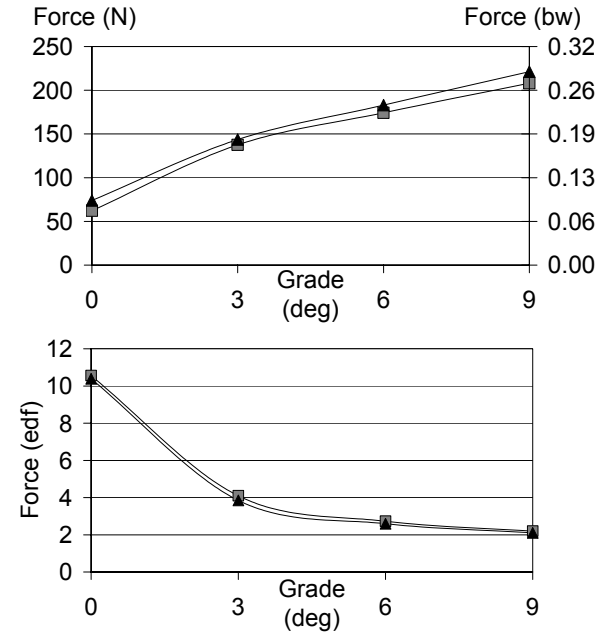


Figure 3: Peak handrim forces in both un-normalized and normalized forms. Triangular markers represent forces with 11.3 kg of mass added to the subject.

SUMMARY

The results of this pilot study suggest that normalizing wheelchair propulsion forces by the effective drag force is an effective and more analytically appropriate method for comparing biomechanics across users of varying body weights.

REFERENCES

Boninger, M.L., Cooper, R.A., *et al.* (1999) Wheelchair pushrim kinetics: body weight and median nerve function. *Arch Phys Med Rehab* **80**, 910-5.

ACKNOWLEDGEMENTS

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