

A SEGMENTAL ANALYSIS OF WORK DURING PROPULSION

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ABSTRACT

Manual wheelchair users are at risk of developing overuse injuries of the arms, which can limit mobility and independence. Reduction of peak forces during the push is expected to reduce the likelihood of developing overuse injuries. One strategy to reduce peak forces during the push is to evenly apply work to the wheel throughout the push. Work input to the wheel during the push was measured for 17 wheelchair users while propelling on a treadmill. Work contribution was found to be least for the first quarter of the push and increasing for each quarter through the third quarter. The fourth quarter contribution of work appeared to be related to workload. As the grade increased from 2% to 8%, the workload also increased from a value less than the third quarter contribution to a value greater than the third quarter contribution. Results suggest that wheelchair users adopt an input work strategy, which takes advantage of the increased mechanical advantage of the arm during the latter stages of the push. The increasing work contribution during the fourth quarter of the push on steeper grades provides insight into how users deal with steeper grades, and may be related to increased forward leaning, decreased propulsion speed, or a decreased recovery time between pushes.

BACKGROUND

Studies in wheelchair propulsion biomechanics aim to better understand the process and serve to direct efforts to reduce the demands on the wheelchair user. A relationship has been established between the characteristics of the forces applied to the handrim during propulsion and incidence of overuse injury. In a study of 34 manual wheelchair users, subjects with symptoms of injury propelled with greater peak forces than those without symptoms of injury (1). The study concludes that reducing peak forces during propulsion should reduce the likelihood of developing injuries.

Ideally, wheelchair users would apply a constant amount of work to the wheel during the push, since it would serve to minimize peak loading during the push. While ideal from a peak loading perspective, this strategy would require an almost instant rate of loading during the beginning of the push, thus subjecting the arm to a potentially harmful loading scenario. Alternatively, the work applied to the wheel could be constant during most of the push, except during the beginning of the push, where it is reduced to allow for a comfortable and safe rate of loading.

RESEARCH QUESTION

Work input to the wheel during the push can be accomplished using a variety of strategies. What strategy do wheelchair users use and what does that indicate about the factors which affect strategy choice?

METHOD

Full-time manual wheelchair users who use a wheelchair with 24-inch rear wheels and have been using their wheelchairs for at least one year were recruited to participate in the study. The subjects' rear wheels were replaced with 24-inch instrumented test wheels. The right test wheel was equipped with a commercially available load cell (ATI, Garner, NC) to measure the torque applied to the handrim and an absolute inclinometer (US Digital, Vancouver, WA) to measure the wheel angle. Signals from the wheel sensors were passed from the wheel through a mercury slip ring and sampled

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by a data acquisition system at 480 Hz (National Instruments, Austin, TX).

Subjects were asked to propel their wheelchair on a treadmill for four one-minute periods at prescribed speeds at different treadmill angles. Prescribed propulsion speeds were chosen to be comfortable for a wide range of wheelchair users. The four grade and speed combinations tested included: 1) 2% grade at 0.94 m/s (2.1 mph), 2) 4% grade at 0.53 m/s (1.2 mph), 3) 6% grade at 0.36 m/s (0.8 mph), and 4) 8% grade at 0.27 m/s (0.6 mph). The first 30 seconds of each propulsion bout was used as an acclimation period. Handrim torque and wheel position data were recorded during the second half of each propulsion bout.

The first 15 pushes from each data file were used in the analysis. For each push analyzed, the amount of time elapsed during the push was divided into four quarter segments. For each quarter, the average torque applied about the wheel hub and the change in wheel angle were calculated. The product of the average handrim torque and the resulting change in wheel angle was used to calculate the average work done during each quarter of the push. Resulting propulsion work for each quarter of the push was compared between conditions using a paired samples t-test with statistical significance set to $p < 0.05$.

RESULTS

Seventeen manual wheelchair users gave written consent and participated in the study. Seven of the subjects were female. The average age of the subjects was 37 years old ($sd=12$) and the average amount of time using a wheelchair was 14 years ($sd=10$).

The average work during each of the four quarters of the push for each of the grade conditions is given in Figure 1. The general trend for all grade conditions shows the amount of work during the first quarter is the least and increases during the second quarter and then increases again during the third quarter. For each of the grade conditions, the differences in work between the first three quarters were statistically significant.

The work during the first quarter for the 8% grade was -0.03 J, just outside the range of the chart in Figure 1, and was statistically different from the other three grades. The first quarter of the push on the 8% grade could be generally characterized by the subject gripping the handrim just as the wheelchair began to roll backwards, rolling backwards for a moment, and then slowly pushing forward, such that the net wheel displacement was zero.

The trend for the fourth quarter contribution of work suggests an increasing contribution of work with increasing grade. The differences in each of the fourth quarter contributions on the four grades were statistically significant. The resulting

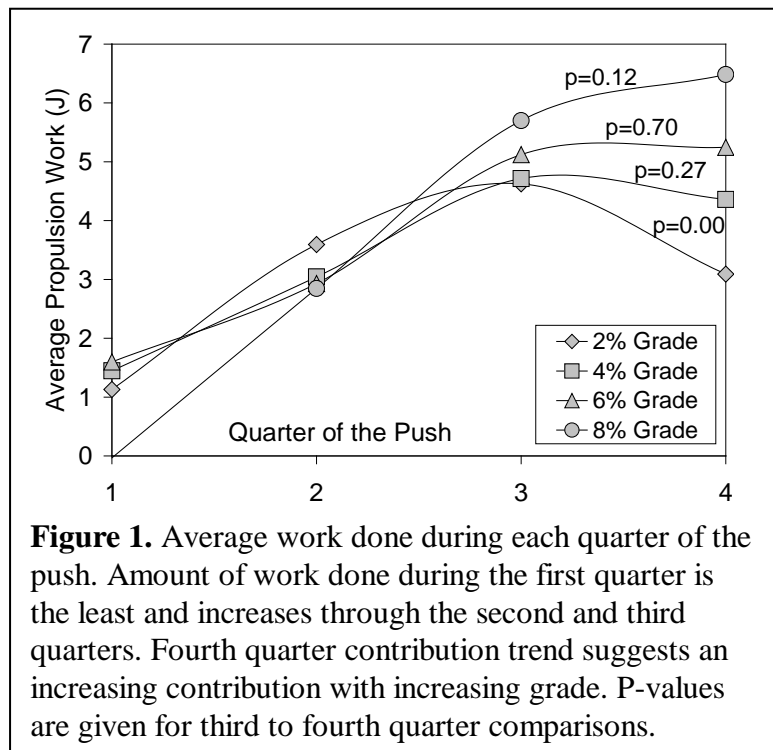


Figure 1. Average work done during each quarter of the push. Amount of work done during the first quarter is the least and increases through the second and third quarters. Fourth quarter contribution trend suggests an increasing contribution with increasing grade. P-values are given for third to fourth quarter comparisons.

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p-values for the comparisons between the third and fourth quarters for each grade are given in Figure 1. The decrease in contribution from the third to the fourth quarter on the 2% grade is significant, and based on the p-value trend is approaching significance for the 8% grade.

DISCUSSION

An optimal strategy to minimize peak demands on the wheelchair user is to apply a constant input work to the wheel during the push, such that the work contribution from each quarter of the push is nearly constant. However, the results of this study indicate that work applied to the wheel during the push is not constant. A reduced work contribution would be expected at the beginning of the push to allow a moderate rate of loading of the arm. Yet, the variation found in this study is much more than a small reduction in work during the first quarter of the push, suggesting that the strategy chosen by wheelchair users is not intended to minimize peak loading during the push.

The strong association between work contribution and push progression suggests that the strategy chosen by wheelchair users is to focus most of the work during the latter stages of the push. Research results from a forward-dynamic propulsion efficiency model suggest that the efficiency of the arm increases toward the end of the push due to an increased mechanical advantage (3). Such an increased efficiency would provide a rationale for wheelchair users to choose to do more of the work during the latter stages of the push.

The trend of increasing fourth quarter contribution with increasing grade may be due to several different factors. As grade is increased, the user leans more forward to prevent tipping. This more forward posture may shift the optimal push efficiency range to later in the push. Also, as grade is increased, speed is reduced. The reduced speed may allow the user to better utilize the last stages of the push. Lastly, as grade is increased, the amount of time the user has to release and re-grip the handrims after a push (recovery time) is reduced. There is a certain minimum amount of time required for the user to reach back to start the next push. As the grade is increased, the recovery time may approach this minimum value, thus requiring users to increase the last quarter work contribution to ensure there is enough time to recover before the wheelchair begins to roll backwards.

Results from this research provide insight into how wheelchair users push during propulsion and what factors may affect their push strategy. Future research in this area will create a foundation for the development of propulsion optimization strategies.

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