

Reduced Finger and Wrist Flexor Activity During Propulsion With a New Flexible Handrim

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ABSTRACT. Richter WM, Rodriguez R, Woods KR, Karpinski AP, Axelson PW. Reduced finger and wrist flexor activity during propulsion with a new flexible handrim. *Arch Phys Med Rehabil* 2006;87:1643-7.

Objective: To test the hypothesis that finger and wrist flexor activity is lower when pushing with a high-friction flexible handrim than with a standard uncoated handrim.

Design: Case series.

Setting: Biomechanics laboratory.

Participants: Twenty-four manual wheelchair users.

Intervention: Subjects pushed their own wheelchairs on a research treadmill set to level, 3°, and 6° grades using both a standard uncoated handrim and a high friction flexible handrim. Propulsion speed was self-selected and held constant between handrim trials. Handrim order was randomized. Finger and wrist flexor muscle activity was measured at the forearm using surface electromyography.

Main Outcome Measures: Electromyographic data were rectified and normalized by each subject's maximum voluntary contraction. Total muscle exertion was determined by integrating the rectified signal over each push. Peak and total muscle exertion for each push were averaged across grade conditions and compared across handrims using a repeated measures *t* test.

Results: The flexible handrim resulted in statistically significant reductions in both peak and total forearm muscle activation. Averaging across all subjects and grade conditions, peak muscle activation was reduced by 11.8% ($P=.026$) and overall muscle exertion was reduced by 14.5% ($P=.016$).

Conclusions: The flexible handrim was shown to require less finger and wrist flexor activity than a standard uncoated handrim for the same propulsion conditions.

Key Words: Rehabilitation; Wheelchairs.

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MANUAL WHEELCHAIR PROPULSION is the primary mode of locomotion for millions of people around the world. There are over a million manual wheelchair users in the United States alone.¹ Over half of the manual wheelchair user population is estimated to have developed upper-limb pain and injury.²⁻⁹ The consequences of such injuries can be significant, including decreased quality of life due to pain, decreased mobility, shoulder and wrist surgeries, and the eventual need for a powered wheelchair. The development of improved propulsion techniques and technologies serves to decrease physical demand on the wheelchair user and thereby preserve upper-limb health.

The handrim found on most lightweight and ultra lightweight manual wheelchairs (K0004, K0005) is an uncoated metal hoop that is rigidly mounted to the outside of each wheel. The handrim is typically hard anodized aluminum; however, alternative materials are available, including stainless steel and titanium. The handrim tubing is generally small (diameter, 19mm) and can be slippery, especially when pushing uphill. Wheelchair users will often resort to pushing on their tires when going uphill to get a better grip. However, since the tire tread can be rough and dirty, this practice is avoided when possible.

A high friction flexible handrim was recently developed that is designed to make it easier and more comfortable to grip the handrim.^a The overall shape of the flexible handrim is contoured to match the shape of the hand when gripping (fig 1A). The flexible handrim is comprised of a high friction elastic membrane that spans between the sidewall of the wheel rim and a standard tubular handrim. The membrane is the only structure coupling the tubular handrim to the wheel. When pushing, the user grips across both the high friction elastic membrane and the tubular handrim (see fig 1B). When braking for an extended period of time, the user only grips the tubular handrim (see fig 1C), which prevents the burning of the hands that generally accompanies handrims with high friction coatings (eg, vinyl, foam).

Because the membrane is elastic, it deforms when it is loaded and it allows the tubular handrim to displace somewhat relative to the wheel. The shape of the membrane is personally customized as it deforms around the thumb when it is gripped. The increased frictional properties along with the improved mechanical coupling are believed to significantly reduce how hard the user needs to grip when pushing.

Currently, instrumentation used in propulsion biomechanics research does not measure grip demand. Instrumented wheels (analogous to forceplates in gait studies) measure how hard and in which directions a force is applied to the handrim, but the internal forces on the handrim itself are ignored. The results are the same regardless of how hard the handrim is squeezed. One reason this instrumentation has not been developed is a concern that introducing sensors between the hand and the handrim will affect the interaction of the hand with the handrim. Electromyography is a method that can be used to gauge grip demand

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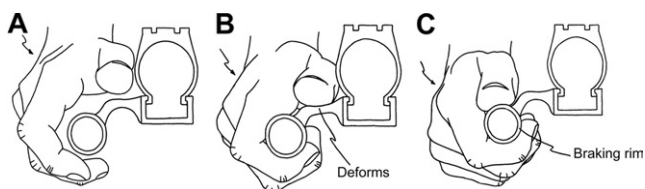


Fig 1. (A) The contoured elastic interface of the flexible handrim matches the shape of the hand as it grips. (B) As the user grips the elastic interface, it deforms around the hand to improve comfort and grip. (C) For extended braking, the user grips only the outer tubular handrim.

on the handrim without affecting the interface between the hand and the handrim.

Requejo et al¹⁰ assessed grip demand for the flexible handrim using fine-wire electromyography for a single wheelchair user pushing on a stationary ergometer for free, fast, and graded conditions. Fine-wire electrodes were inserted into the flexor digitorum sublimis, opponens pollicis, and the flexor pollicis brevis. The greatest reductions in muscle activity were seen for the free and fast conditions, where collectively muscle activation was reduced by 61.5%. For the graded condition, muscle activation was only reduced for the finger flexors (flexor digitorum sublimis), with a 43% reduction. Results of the study strongly suggested that the flexible handrim reduces grip muscle activity during wheelchair propulsion. The primary limitation of the study was the use of a single subject. The purpose of this study was to test the hypothesis that grip muscle activity is lower when pushing with a high friction flexible handrim than with a standard uncoated handrim.

METHODS

Participants

The protocol received institutional review board (Western IRB) approval prior to recruiting subjects for the study. A convenience sample of 25 manual wheelchair users was recruited to participate in the study from an internal database of potential and experienced test subjects. We did not have pilot electromyographic data to estimate statistical power a priori. However, a population of at least 20 subjects is a required threshold for consideration in the Paralyzed Veterans of America clinical practice guidelines on the preservation of upper-limb function following spinal cord injury (SCI).¹¹ Inclusion requirements included: (1) use of a manual wheelchair as the primary means of mobility, (2) full use of the arms and hands, (3) comfortable propelling a wheelchair continuously for periods of up to 2 minutes, (4) use of a wheelchair equipped with 61cm (24-in) diameter quick-release rear wheels, and (5) no medical conditions that might be aggravated by wheelchair propulsion or moderate exercise periods. All subjects read and signed the IRB-approved consent form prior to participation.

Experimental Protocol

Subjects transferred out of their wheelchairs and we replaced their rear wheels with propulsimeter instrumented test wheels.¹² Subjects then transferred back into their wheelchairs and we fitted them with electromyography electrodes on their right forearm. Subjects were instructed to grip the right handrim as tightly as possible while electromyographic measurements were taken, representing the subject's maximum voluntary contraction (MVC).

Subjects were loaded onto a large multigrade research treadmill and were fitted with a safety system. The safety system was comprised of rope and repelling hardware. A spotter at the front of the treadmill controls the rope slack to allow the wheelchair freedom of movement while preserving the ability to quickly secure it if necessary. Subjects became acclimated to the treadmill by pushing at a variety of speeds for level, 3°, and 6° grades and then chose their comfortable speed for each grade. The acclimation period was completed using a standard handrim.^b The standard handrim was uncoated and hard anodized aluminum with a tubing diameter of 19mm. This handrim is sold on wheelchairs from many of the major wheelchair manufacturers. It is also the same handrim that was used in the construction of the outer component of the flexible handrim. The first test handrim was chosen by drawing a number from a cup. The first test handrim pair was installed onto the subject's wheelchair. After a 5-minute rest period, subjects completed a single propulsion bout, including 35 pushes on level, 30 pushes on the 3° grade, and 25 pushes on the 6° grade, all at their self-selected comfortable speeds. The number of pushes decreases with grade because it is more difficult for subjects to push uphill. During each propulsion bout, right forearm electromyography was measured and the loading on the right handrim was measured using the right propulsimeter. The experimental setup is shown in figure 2. After a second 5-minute rest period, subjects repeated the propulsion bout using the second pair of test handrims.

Instrumentation

Although the use of fine-wire electromyography allows discrete grip muscle activity to be measured, it also requires that subjects have fine-wire electrodes invasively inserted into their forearm and hand muscles with a needle. Surface-mount electromyography offers a noninvasive alternative that is more conducive to a larger subject study. Surface electromyography has been used previously to study differences in forearm electromyographic activity between a standard handrim and a new



Fig 2. The experimental setup used in this study included a research treadmill, a surface electromyographic measurement system, and an instrumented wheel.

handrim design.¹³ As a result, surface electromyography was chosen for this study. The primary disadvantage of surface electromyography for this study was that finger flexor activity could not be distinguished from wrist flexor activity.

We made surface electromyographic measurements using the Biopac MP150 along with an electromyography 100C module.^c Circular Ag-AgCl electrodes with a 10-mm diameter were used. The skin was prepared by cleansing with alcohol and applying conductive gel. Electrodes were spaced by approximately 10cm across the flexor muscles, starting approximately 5cm from the medial epicondyle, along the longitudinal axis of the forearm. A ground electrode was located at the wrist. Overall muscle activity was contributed to by the flexors of the wrist and fingers, including: flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum superficialis, flexor pollicis longus, and flexor digitorum profundus. The signals were processed with a differential amplifier (bandwidth, 10–500Hz; input impedance, 1G μ ; common mode rejection ratio, 110dB at 60Hz; gain, 1000). An external trigger was used to ensure that the electromyographic data collection was synchronized with the kinetic data collection. The sampling rate was set to 1000Hz. Linear envelopes of electromyographic signals were constructed by rectifying and low-pass filtering, using a fourth-order recursive Butterworth filter with a 10-Hz cutoff frequency.¹⁴ The conditioned signal was then resampled at a frequency of 200Hz, corresponding to the sampling rate of the kinetic data. Electromyographic data were normalized by each subject's MVC and multiplied by 100, resulting in units of percentage of MVC.

The propulsometer is a custom instrumented wheel that is capable of measuring the dynamic 3-dimensional forces and moments applied to the handrim during propulsion. The propulsometer measures handrim loads using a commercially available 6 degree-of-freedom load cell.^d Handrim kinetics were measured at 200Hz and filtered using a fourth-order Butterworth digital filter with a 20-Hz cutoff frequency.¹⁵ The dynamic offset was then removed from each channel and the calibration matrix applied, resulting in conditioned force and torque outputs.¹⁶

Data Reduction

We identified pushes by periods of active loading on the handrim. The last 20 pushes from each grade condition were used in the analysis.¹⁷ For each push analyzed, the maximum electromyographic magnitude was determined. Overall finger and wrist flexor activity (integrated electromyography) was determined by integrating the time-varying electromyographic signal over each push. Integrated electromyography was numerically approximated using the trapezoidal rule with a uniform time element of 1/200th of a second. Maximal electromyographic and integrated electromyographic values were then averaged over each 20-push set, as well as across all three 20-push sets, for each handrim condition. Data reduction was automated using custom programs developed in Matlab.^e

Statistical Analyses

We calculated descriptive statistics for the peak and integrated electromyographic biomeasures for each handrim condition over the subject population. The data were tested for normality using a Kolmogorov-Smirnov test. Differences between the standard handrim and the flexible handrim were assessed using a 2-tailed paired-sample *t* test for the average across all 3 grades. Differences were determined to be statistically significant for *P* less than .05. All statistical tests were completed using SPSS statistical software.^f

RESULTS

Participants

Twenty-four of the manual wheelchair users recruited for the study gave written consent and participated in the study. One subject recruited for the study cancelled due to a schedule conflict. Six subjects were women. The average age \pm standard deviation (SD) of the subjects was 35 \pm 11 years old and the average wheelchair experience was 16 \pm 10 years. The average weight of the subjects was 71.4 \pm 16.2kg. Twenty-two subjects had an SCI at or below T6. Two of the subjects had spina bifida.

Propulsion Conditions

All subjects were able to comfortably complete the protocol. The average self-selected speeds \pm SD chosen by the subjects were 1.21 \pm 0.24m/s for the level condition, .77 \pm .18m/s on the 3 $^\circ$ grade, and .45 \pm .16m/s on the 6 $^\circ$ grade.

Forearm Electromyography

A sample plot of an electromyographic linear envelope taken over a single push for subject S23 is shown in figure 3 for both the standard and flexible handrims while on the 6 $^\circ$ grade. In this comparison, electromyographic activity is noticeably lower when using the flexible handrim. The data were found to be normally distributed (significance at $>.18$). Results for maximum electromyography and integrated electromyography are given in figures 4 and 5, respectively. Averaging across all grade conditions, the flexible handrim was found to reduce both peak muscle activation and overall muscle exertion. For the population, maximum electromyographic activity was reduced by 11.8% ($P=.026$) and integrated electromyographic activity was reduced by 14.5% ($P=.016$). The trend for each grade condition followed that of the overall average. However, differences between the individual grade results were not statistically evaluated.

DISCUSSION

This study represents the first investigation of finger and wrist flexor demand with the flexible handrim in a population

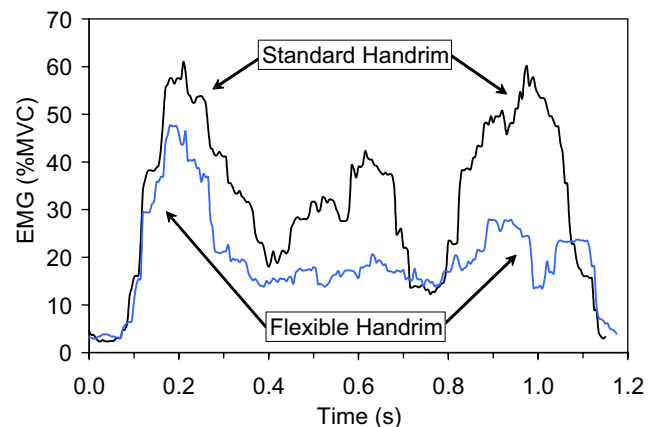


Fig 3. Linear envelopes of the electromyographic (EMG) signals taken over a single push for subject S23 with the standard and flexible handrims while on the 6 $^\circ$ grade. Electromyographic activity is noticeably lower when using the flexible handrim. This trimodal shape was seen with some consistency. It suggests that grip is not constant during the push and that it is highest at the beginning and end of each push. Grip may be lowest in the middle of the push because the user can generate the necessary friction by pushing down radially into the handrim within that angular range.

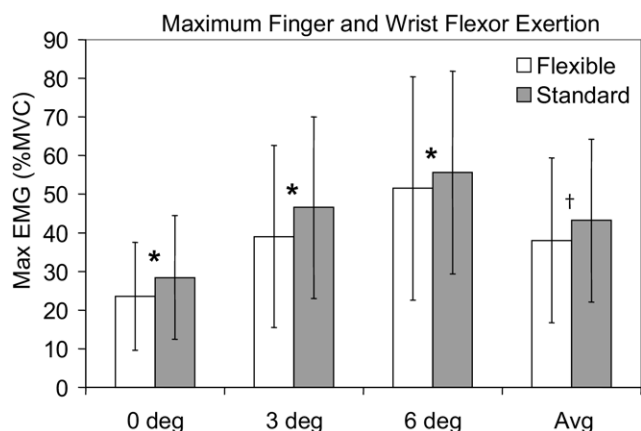


Fig 4. Maximum finger and wrist flexor activity for the population of wheelchair users. The average (Avg) condition represents an average across all grades. NOTE. Error bars represent SD. *Not statistically analyzed; †P=.026.

of wheelchair users. The flexible handrim was found to significantly reduce muscular activity over a range of grades. The results of this study support the findings by Requejo et al¹⁰ for a single subject. When isolating the finger flexor results for free and graded conditions, Requejo found that the flexible handrim reduced maximum exertion by 54% and 43%, respectively. The reductions were considerably larger than those found for the population in this study.

There were considerable differences found across individuals in this study. In reviewing maximum electromyographic activity for level propulsion, 12 subjects were found to have reductions below 10% and the remaining 12 above 10%. Two of those subjects were found to have reductions above 50%, with the largest reduction being 62.5%. It is possible that the individual subject in the Requejo study happened to be part of a small percentage of users who particularly benefit from the flexible handrim grip improvements. However, the differences may also be due to the surface electromyography approach used in this study. With surface electromyography, finger flexor activity cannot be differentiated from wrist flexor activity. Although the wrist has been shown to primarily be in extension during the push,¹⁸ wrist flexors have been shown to be active in co-contraction.^{14,19} If wrist flexor activity is unaffected by the flexible handrim, then the reductions in finger flexor activity measured by surface electromyography would essentially be diluted by the baseline wrist flexor activity. A fine-wire electromyography study of finger flexor activity for a population of wheelchair users would provide a more accurate assessment of the grip benefits provided by the flexible handrim.

Baldwin et al¹³ used surface electromyography to investigate forearm electromyographic activity for a standard handrim and a beta prototype of the Natural-Fit handrim.⁵ The Natural-Fit handrim is a large oval tubing handrim with a recessed trough filling the gap between the handrim and the wheel rim. Maximal electromyographic activity did not differ between the Natural-Fit prototype and the standard handrim. The researchers did not speculate why the Natural-Fit did not reduce grip demand. The Natural-Fit design is very different from the flexible handrim design. Although the Natural-Fit provides a high friction coating along a portion of its grip surface, the grip surface is not flexible. As a result, it does not deform around the hand to improve the mechanical coupling between the hand

and the handrim, as the flexible handrim does. Differences between the electromyographic results of this study and those of the Natural-Fit study are likely due to these fundamental design differences.

Improving the ergonomics of gripping during wheelchair propulsion is important. The results of this study suggest that on average users are gripping at 55.5% ± 26.2% of their maximum grip when pushing up a 6° hill. While these results are a mix of both finger and wrist flexor activity, they reveal a significant demand on the wheelchair user.

Study Limitations

There were several limitations to the results of this study. Only 1 standard handrim design was studied, and although the vast majority of standard handrims are physically similar, there may be subtle differences across handrim manufacturers. Only wrist and finger flexor muscle activity was measured. It is possible that the reduced muscle activity found when using the flexible handrim could result in an increase in muscle activity elsewhere in the upper extremity. The study was done on a treadmill, which from an inertial perspective is equivalent to overground propulsion, but it is not overground propulsion. Propulsion on the treadmill enforces a constant propulsion speed that does not occur when pushing over ground. The results of this study represent an average effect on muscle activity. It is not clear what aspect of the flexible handrim design leads to this reduced activity. It may be the increased frictional properties, the compliant shape or a combination of the 2.

There is a need to develop the research methods, models, and instrumentation required to investigate grip biomechanics during propulsion. Currently, the only studies to investigate grip demand have used electromyography as the outcome measure. However, the same level of muscle activation can result in varying levels of grip force production, depending on the posture of the hand. With new designs being developed that dramatically alter the shape of the handrim grip surface, it is important that biomechanic effects of these changes be evaluated. The consequences of handrim shapes that put the hand at a biomechanic disadvantage could do more harm than good and lead to an increase in repetitive stress injuries.

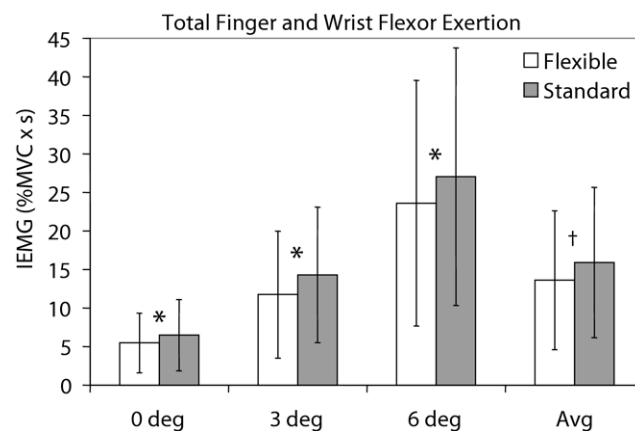


Fig 5. Total finger and wrist flexor activity for the population of wheelchair users. The average condition represents an average across all grades. NOTE. Error bars represent SD. *Not statistically analyzed; †P=.016.

CONCLUSIONS

The flexible handrim was shown to reduce finger and wrist flexor activity for a population of wheelchair users, over a range of grades. Peak activity was reduced by an average of 11.8% and overall activity was reduced by an average of 14.5%. Although these effects may be considered relatively small in the short term, over years of cumulative wheelchair use, they may be influential in preserving the upper-limb health of the wheelchair user.

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Suppliers

- a. Spinerogy, 116 Noland Ct, Lyons, CO 80540.
- b. Sun Components, Inc, 6750 W Florist Ave, Milwaukee, WI 53218.
- c. Biopac Systems Inc, 42 Aero Camino, Goleta, CA 93117.
- d. ATI Industrial Automation, Pinnacle Pk, 1031 Goodworth Dr. Apex, NC 27539-3869.
- e. The MathWorks, 3 Apple Hill Dr, Natick, MA 01760-2098.
- f. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.
- g. Three Rivers Holdings, 1826 W Broadway Rd, Ste 43, Mesa, AZ 85202.

strated in the study by Riew et al.³ This is certainly the worst-case scenario. If a selective nerve root block accelerates the healing process then that would be an even more compelling reason to perform this therapeutic technique.

In summary, we categorically concur with Novak and Nemeth and appreciate their re-emphasis of these 2 issues.

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Corrections

In the Results section of the abstract (p1964), in table 2 (p1965), and in the Results of the study (p1966) of Wang YH, Huang TS, Liang HW, Su TC, Chen SY, Wang TD. Fasting serum levels of adiponectin, ghrelin, and leptin in men with spinal cord injury. *Arch Phys Med Rehabil* 2005;86:1964-8, all reporting of serum adiponectin and adiponectin levels should be in micrograms per milliliter (not nanograms per milliliter).

On page 1646 of Richter WM, Rodriguez R, Woods KR, Karpinski AP, Axelson PW. Reduced finger and wrist flexor activity during propulsion with a new flexible handrim. *Arch Phys Med Rehabil* 2006;87:1643-7, we misidentified the handrim, used and reported in a proceedings abstract by Baldwin et al (reference 13 in our study), as a beta prototype of the Natural-Fit handrim by Three Rivers Holdings. We have subsequently learned that the ergonomic handrim used by Baldwin was heavier and constructed of different materials than the prototype we purchased. Additionally and more importantly, the design of the handrim used in Baldwin differs substantially from the current Natural-Fit handrim that is now on the market. Consequently, the results of the Baldwin study do not apply to either the early version of the Natural-Fit handrim that we have or to the current version of the product. Also, the comparisons we drew between the flexible handrim design and the Natural-Fit handrim are irrelevant and should be disregarded. We apologize for any damage this may have done to the reputation of the Natural-Fit handrim or Three Rivers Holdings. The misrepresentation was unintentional.

We also selectively interpreted Baldwin's discussion of results and chose only to include those results we felt were directly relevant to our study. That was short sighted; we should have discussed the complete set of results. As we noted, Baldwin did not find significant differences in electromyographic measurements between the handrim designs. However, Baldwin did find increased resultant forces on the handrim with the ergonomic handrim design. Based on these data, Baldwin suggested that the ergonomic rim allowed for greater force and moment application to the pushrim while not increasing muscle activity.