

# Vinyl-Coated Handrim Biomechanics: Balancing Ergonomic Pros and Cons

W Mark Richter, Russell Rodriguez, Kevin R Woods, and Peter W Axelson  
Beneficial Designs BioMobility Lab, Nashville TN

## ABSTRACT

The use of a high friction vinyl-coated handrim makes gripping the handrim easier when pushing. Use of a vinyl-coated handrim has been shown to reduce metabolic demand when compared to a standard handrim for the same propulsion task. The effect of a vinyl coating on handrim biomechanics has not been adequately studied. In this study, 25 wheelchair users used both a standard handrim and a vinyl-coated handrim to propel on a treadmill set to three different grade conditions; 0, 3, and 6-degrees while handrim biomechanics were measured. Power generated during the push was found to be increased for each grade condition, allowing the user to push less and coast more. However, handrim force magnitudes and rates of loading were also increased, placing the user at greater risk of developing repetitive stress injuries. It is recommended that use of a high friction handrim grip surface be coupled with a compliant or low impact handrim interface to reduce the adverse effects of increased loading on the upper extremity.

*Keywords:* wheelchair, propulsion, biomechanics, handrim, vinyl, efficiency, uphill, grade, force, CTF

## BACKGROUND

Handrims are the primary interface by which the wheelchair user pushes, brakes, and turns the wheelchair. The standard handrim is an anodized aluminum tubing hoop, mounted offset to the side of each wheel. The standard handrim is relatively slippery. As a result, the user must grip it tightly to keep the hand from slipping on the handrim during the push. A vinyl-coated handrim is a standard handrim coated with vinyl. The vinyl coating provides increased friction between the hand and the handrim. As a result, the user does not have to grip as hard during propulsion. Decreasing physical demand on the wheelchair user during propulsion is important since it may serve to delay or prevent the development of secondary repetitive stress injuries of the upper extremity. In a study of 9 wheelchair users pushing on a treadmill set to a range of grade conditions, we found the use of a vinyl-coated handrim resulted in an 9% average decrease in metabolic demand during propulsion [1]. The decrease in metabolic demand was hypothesized to be the result of reduced gripping demands as well as an increased mechanical efficiency of the push. In a pilot study of handrim biomechanics, Koontz *et al.* found that use of a vinyl-coated handrim on a wheelchair ergometer reduced the average peak force applied to the handrim during propulsion by 10% [2]. Unfortunately, the vinyl coating is a very poor conductor of heat. As a result, the heat generated during braking quickly exceeds the tolerance threshold of the user and the user has to let go of the handrim. In the same study of 9 wheelchair users, we found that when using a standard handrim, users could brake downhill on the treadmill for an average 109 seconds before letting go while they could only brake for 9 seconds using the vinyl-coated handrim [1]. Handrim surface temperature was also measured during the study. A handrim temperature profile for one subject is shown in Figure 1. It can be seen that the temperature climbs slowly for the standard handrim, while it rapidly heats up with the vinyl-coated handrim. Users let go at a lower temperature because the hand rather than the handrim is absorbing the heat. The use of gloves can allow a user to get down hills without burning his/her hands.

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Insert **Figure 1** here

## RESEARCH QUESTION

It is clear from the pilot studies that have been done that there may be both ergonomic benefits as well as

adverse side effects to the high friction vinyl coating. Better understanding of these effects on the user will allow designers to know what attributes should be integrated into new ergonomic handrim designs. The pilot study of handrim forces by Koontz *et al.* provided insight into the biomechanical benefits of pushing with a vinyl-coated handrim, but it was not a comprehensive study. The study was limited to propulsion on an ergometer, which only simulates propulsion on a level surface. The purpose of this study was to comprehensively assess vinyl-coated handrim biomechanics over a range of clinically relevant propulsion conditions and to determine what, if any biomechanical benefits there are for the user.

## METHODS

Full-time manual wheelchair users with full use of their upper extremities were recruited to participate in the study. All subjects read and signed an IRB approved consent form prior to participation. The subjects' rear wheels were replaced with instrumented test wheels. The right test wheel was equipped with a commercially available 6DOF load cell (ATI, Garner, NC) to measure the force and moment vectors applied to the handrim. Upper extremity and wheel kinematics were measured using a 3D active marker motion capture system (Phoenix Technologies). Markers used in this analysis were placed on the wheel (3) and on the 3<sup>rd</sup> MP joint of the users right hand. The 3<sup>rd</sup> MP joint was used as an estimate of the point of contact of the hand on the handrim. Subjects were asked to propel their wheelchair on the treadmill using a standard handrim and to determine a comfortable propulsion speed over three grade conditions, increasing from level to 3 degrees and finally to 6 degrees of incline. After a 15-minute rest period, subjects were then asked to again propel using one of either the vinyl-coated handrim or the standard handrim. Handrim order was randomized. Subjects propelled at their self-selected speeds for 35 pushes on level, 30 pushes at 3 degrees, and finally 25 pushes at 6 degrees. 15-minute rest periods were given between propulsion bouts. Kinetic and kinematic measures were made continuously over each handrim trial. The experimental setups for the level and 6-degree grade conditions are shown in Figure 2. The last 20 pushes from each grade condition were used in the analysis. The force vector was translated from a lab fixed frame of reference to a contact point frame of reference using the 3<sup>rd</sup> MP marker as the contact point. The resulting force components were radial, tangential and lateral with respect to the handrim. For each push analyzed, the peak force components were determined and averaged over all 20 pushes. Similarly, characteristic values for average force components, maximum rate of loading, Contribution of Tangential Force (CTF), push angle, push frequency, recovery to push time ratio, and power per push were also determined. Biomechanical metrics were then compared between the handrim conditions using a paired samples t-test and determined to be statistically significant for  $p < 0.05$ .

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Insert **Figure 2** here

## RESULTS

Twenty-five manual wheelchair users gave written consent and participated in the study. Seven of the subjects were female. The average age of the subjects was 36 years old (sd=11) and the average wheelchair experience was 17 years (sd=11). Each of the subjects was able to complete the protocol without undue stress, discomfort, or fatigue. The resulting average self-selected propulsion velocities were 1.13 m/s (sd=0.23), 0.77 m/s (sd=0.17), and 0.44 m/s (sd=0.17) for the level, 3-degree and 6-degree grade conditions respectively. The resulting biomechanical metrics are given in Tables 1 and 2. An asterisk denotes those results that were statistically different between the handrims. The results show that maximum force components tended to be higher rather than lower when using the standard handrim, as was earlier found [2]. The increases in force magnitudes were significant on the 3-degree grade in all except the radial force component. The maximum moment was also significantly higher on the 6-degree

grade. The maximum rates of loading were also found to be higher, with significance found on the 3 and 6-degree grades for all components except lateral. While there was a trend of decreased push angle, it was not found to be significant. Average loading on the handrim followed a similar pattern as the maximum values, being higher for the vinyl-coated handrim over the standard handrim, which reached significance for the majority of the components and grade conditions. CTF appeared to be consistently higher for the vinyl-coated handrim but was not found to be statistically significant. There were no significant changes to push frequency. Users pushed with more power per push when using the vinyl-coated handrim at all the grade conditions. The increased varied from 6% on the level to 12% on the 6-degree grade. As a result users typically spent less time pushing and more time coasting, as reflected in the push to recovery time ratio, which was significantly higher for the 3 and 6-degree grades.

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 Insert **Table 1 and 2** here

## DISCUSSION

This study provides evidence that use of a high friction handrim may actually increase the forces and moments on the handrim during propulsion. These results are contrary to what was found in an earlier pilot study [2]. The reason for the increase appears to be that the increased friction allows the user to grip better, and he/she takes advantage of that by pushing harder and coasting more. This is evidenced by the increased push to recovery time ratio, while push frequency remained relatively unaffected. In addition to higher forces, the rate of loading was also increased. Both magnitude and rate of loading on the handrim have been identified as targets to reduce in the biomechanics research to date. Based on the fact that metabolic demand was reduced when using the vinyl-coated handrim [1], the potential ergonomic benefits of high friction seem desirable for propulsion. However, the adverse increases in loading could accelerate the development of repetitive stress injuries. Use of a compliant or low impact handrim interface has been found to reduce magnitude and reduce rate of loading for select propulsion conditions [3]. It is likely that use of a vinyl-coated handrim in combination with a compliant handrim interface would provide the benefits of the high friction coating without the adverse increases in magnitude and rate of loading. It is recommended that any new ergonomic handrim design that integrates a high friction grip surface test for increases in magnitude and rate of loading over a range of clinically relevant propulsion conditions prior to distribution to the wheelchair user population.

## REFERENCES

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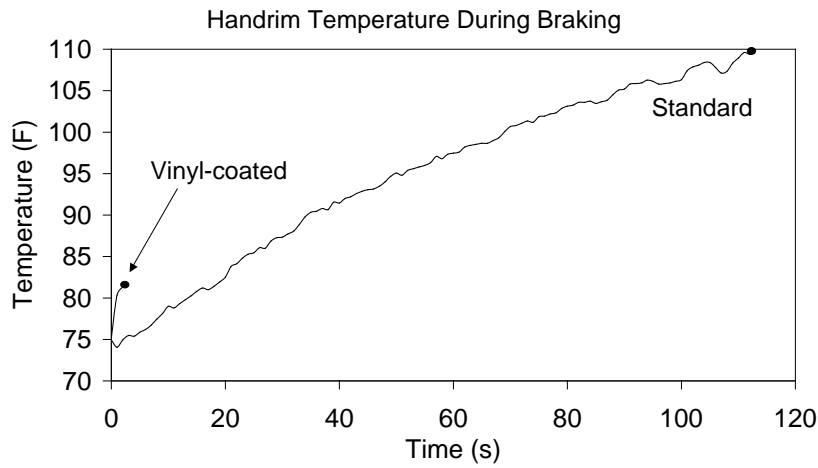
W Mark Richter

mark@beneficialdesigns.com

Nashville TN

(615) 837-6902

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 Figure 1.  
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**Figure 1.** Handrim surface temperature measured during braking for a single subject in a previous study. It can be seen that the standard handrim heats up slowly, which the vinyl-coated handrim heats up almost instantaneously. The user lets go very quickly.

Alternative Text Description for Figure 1: Plot shows the standard handrim temperature rises slowly while the vinyl-coated one rises quickly.

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Figure 2.  
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**Figure 2.** The experimental setup included the subject pushing his/her own wheelchair on a research treadmill. The instrumented test wheels allow the forces and moments applied to the handrim to be measured. Motion capture markers were used to track the location of the wheel and 3<sup>rd</sup> MP joint of the hand.

Alternative Text Description for Figure 2: Two pictures of a test subject pushing on the treadmill, one at level and the other on a 6-degree grade.

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 Table 1.  
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**Table 1.** Biomechanical results for the standard and vinyl-coated handrims on level, 3 degree, and 6 degree grade conditions. Outcomes include maximum radial force (Fr), tangential force (Ft), lateral force (Fl), moment applied about the axle (Moment), rate of loading for each of those force components, as well as the angle through which the users pushed on the handrims (Push Angle).

\* =  $p < 0.05$

Condition	Max Fr (N)	Max Ft (N)	Max Fl (N)	Max Moment (Nm)	Max dFr/dt (N/s)	Max dFt/dt (N/s)	Max dFl/dt (N/s)	Push Angle (deg)
Standard (level)	45.5	25.4	13.9	8.6	926	391	379	107.6
Vinyl (level)	44.3	26.0	13.0	9.0	929	407	377	104.3
Standard (3 deg)	71.7	59.4	22.9	19.4	1389	625	524	97.2
Vinyl (3 deg)	76.0	64.6*	20.5*	21.6*	1560*	778*	569*	96.1
Standard (6 deg)	83.3	80.8	29.2	25.5	1706	928	639	80.6
Vinyl (6 deg)	85.3	84.9	26.4	27.9*	1918*	1185*	673	79.4

Alternative Text Description for Table 1: Table of numbers shows trends in higher max forces and rates of loading for the vinyl-coated handrim.

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 Table 2.  
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**Table 2.** Biomechanical results for the standard and vinyl-coated handrims on level, 3 degree, and 6 degree grade conditions. Outcomes include mean radial force (Fr), tangential force (Ft), lateral force (Fl), moment applied about the axle (Moment), the Contribution of Tangential force, or mechanical efficiency of the push (CTF), push frequency or cadence, the ratio of push to recovery time, as well as the power generated during the push. \* = p<0.05

Condition	Mean Fr (N)	Mean Ft (N)	Mean Fl (N)	Mean Moment (Nm)	Mean CTF ( )	Push Frequency (N/s)	Push/Recovery Time Ratio (N/s)	Push Power (W)
Standard (level)	20.3	9.6	5.4	4.0	0.28	1.09	0.46	7.8
Vinyl (level)	21.4	10.5	4.9*	4.2	0.30	1.11	0.46	8.3*
Standard (3 deg)	37.3	28.1	10.5	10.5	0.36	1.08	0.28	19.0
Vinyl (3 deg)	41.4*	32.5*	8.4*	12.1*	0.39	1.06	0.30*	21.1*
Standard (6 deg)	40.0	43.8	12.9	15.3	0.47	0.86	0.15	18.7
Vinyl (6 deg)	44.5	48.8*	11.0	17.4*	0.50	0.87	0.17*	20.9*

Alternative Text Description for Table 2: Table of numbers shows trends in higher mean forces, CTF, and power for the vinyl-coated handrim.