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Users' responses to contoured wheelchair handrims*

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Abstract—The responses of 28 spinal cord injured wheelchair users who tested a contoured handrim design were analyzed. Paraplegics, who had stronger grip strength, preferred the contoured design compared with their own handrims in 10 of 12 circumstances of use, as well as according to overall assessment. Most indicated they would pay the estimated additional cost to produce the test shape, which is designed for increasing the contact between hand and rim. Quadriplegics, with weaker and more viable grips, gave mixed responses. This opinion study illustrates some of the problems encountered in evaluation of new equipment for disabled persons.

BACKGROUND

Testing new equipment for people with disabilities is essential to patient and equipment assessment given the proliferation of new designs in the past decade (2). Criteria for performance vary according to the characteristics of the product as well as of the user groups. In general, once it is established as safe, specialized equipment may be either compared with physical performance standards or rated by users themselves. When equipment is marketed without formalized testing, its success depends solely on its sales performance, but since many new equipment designs are intended for a small user population, consumer input into product development is more difficult to obtain and analyze than for products developed for the general population.

Wheelchair handrims are important to mobility because they constitute the site of transmission of energy from the user to the chair. Torque generated at the wheels is directly proportional to the force a person can apply at the handrims, since the torque is product of that force and the radial distance of the handrim to the center of rotation of the wheels. Individual grip characteristics control the force transmission from user to wheelchair. A strong grip provides a firm linkage for high force application, as is necessary in sports model wheelchairs with small handrim diameters. In this study a new wheelchair handrim design increasing hand surface contact for better force transmission was tested by experienced paraplegic and quadriplegic manual wheelchair users. For wheelchair users who prefer to grip the tire, the handrim is of little significance, of course.

METHODS

The prototype contoured handrims made of yachting-quality plywood received nine coats of polyurethane for a smooth finish. The material differences between these and the standard steel handrims were obvious to the experienced wheelchair users who consented to participate in this study. The design was granted a patent (U.S. Patent 4, 366, 964) since the testing was completed, but has not been licensed for commercial production at this

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writing. **Figures 1a** and **1b** illustrate the differences between the prototype rim and a standard round cross-section steel handrim.

Each subject answered questions about prior wheelchair experience and medical history. All were male spinal cord injured patients (21 paraplegics and 7 quadriplegics) followed at our center ranging in age from 21 to 65 years. They were all examined in their wheelchairs with particular attention to grip characteristics including hand size and strength, measured at the second setting on a Jamar adjustable grip dynanometer (Asimow Corp., Los Angeles, CA). This gives grip strength of the hand squeezing bars 1 1/2 inches (3.7 cm) apart. Other aspects of the man-machine interface measured included stroke length relationship of arm length to wheel diameter and handrim size and surface; none of these factors related to preference and are not presented. The clinical features are summarized in **Table 1.**

Users' wheelchair handrims were replaced by one of two pairs of prototype rims that more closely matched those of the user. These were 20 and 21 in (50.8 and 53.3 cm) in diameter; all wheels were 24 inches (61.0 cm) in diameter.

The subjects own handrim spacers were used so that the distance between rim and wheel was not affected.

Table 1
Clinical features of subjects

Level of Injury	
C5–C6	2
C7–C8	5
T1–T6	6
T7–L1	15
Completeness	
Motor	
paraplegics	21
quadriplegics	2
Sensory	
paraplegics	13
quadriplegics	2

The subjects were told to use the handrims for several days so that they could become familiar with the contour of the handgrip and would be able to comment on the differences between these and their own handrims. Many of these healthy volunteer subjects were admitted to our center for routine followup of the urinary tract. Others who lived nearby were well patients known to our clinics. All used the rims for at least 2 days; many used them for 1 week. Their responses to a questionnaire were analyzed. They were asked to rate their rims as "better,"

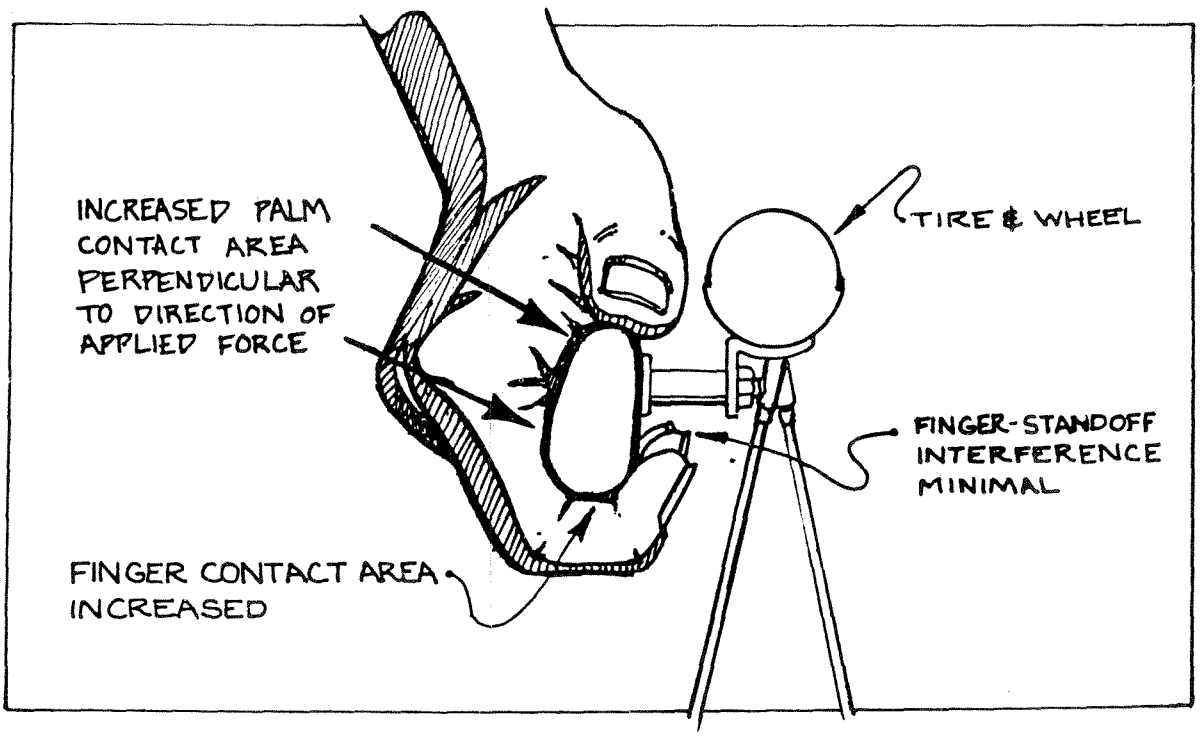

Figure 1a
Crossection comparison

"worse," or "not different from their own" in several circumstances of use and to compare overall comfort and impact on effort in pushing; they were also asked whether they would pay estimated costs for changes necessary to produce the new design. Statistical procedure is cited where applicable in reporting the results; analysis was done using the CP/M based statistical package, MicroStat 2.0 (Ecosoft, Inc.; Indianapolis, IN 46268).

RESULTS

For analysis, the subjects were divided into two groups: paraplegic, with average of left and right grip strength of at least 67 lb (298. N) and quadriplegic, with an average strength of no more than 60 lb (266.9 N). Although the average grip strength provides a discriminant function for the clinical diagnosis, paraplegia or quadriplegia there is some overlap between the stronger hand of two low quadriplegics and the weakest paraplegic subject's hands.

The paraplegic group preferred the prototype rim designed over their own in all but 2 of 12 circumstances of use. The numbers of paraplegics responding favorably are represented in the unshaded areas of the bar graphs of **Figure 2,** the negative responses are the darkened areas. For chi square analysis of the probability that the two groups' responses differ from random yes or no answers, the indifferent responses were not considered. In all categories of use except braking and going down ramps, the response was significant. If the indifferent answers are considered with the negative responses, rather than with the "not applicable" responses, the test rims were still favored in all circumstances of use except the two circumstances where the other comparison failed to show significance. The inability of the wood rims to conduct frictional heat away from site of hand contact was the reason respondents preferred their old rims while going down ramps and braking.

In a general comparison between their own rims and the test rims for overall comfort, only 3 of 21 paraplegics preferred their own rim shapes. In a similar comparison for effort involved in pushing there were only five who indicated that their own rims required less effort for pushing. There were no clearly distinguishing features of the negative responders in terms of grip, arm length, or wheelchair experience.

The designer estimated that add-on cost for materials and retooling for production of the new design would be

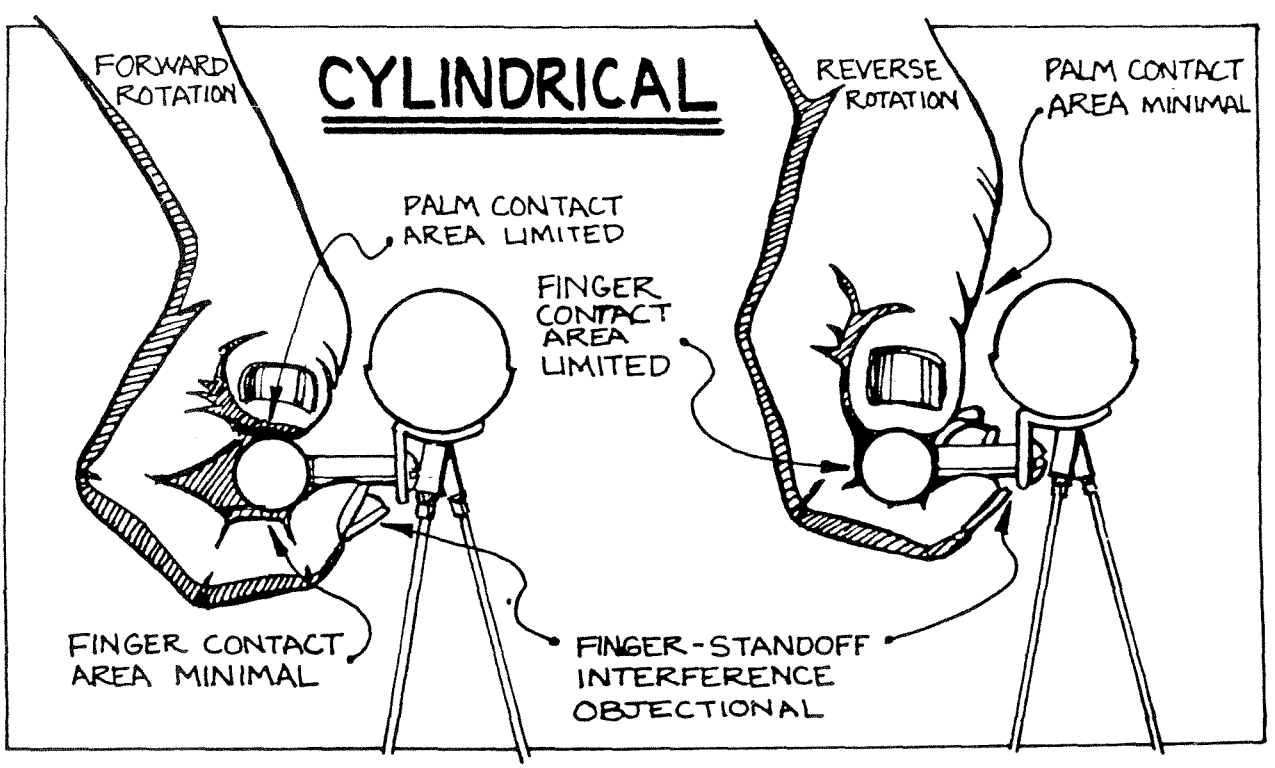

Figure 1b
Cylindrical comparison

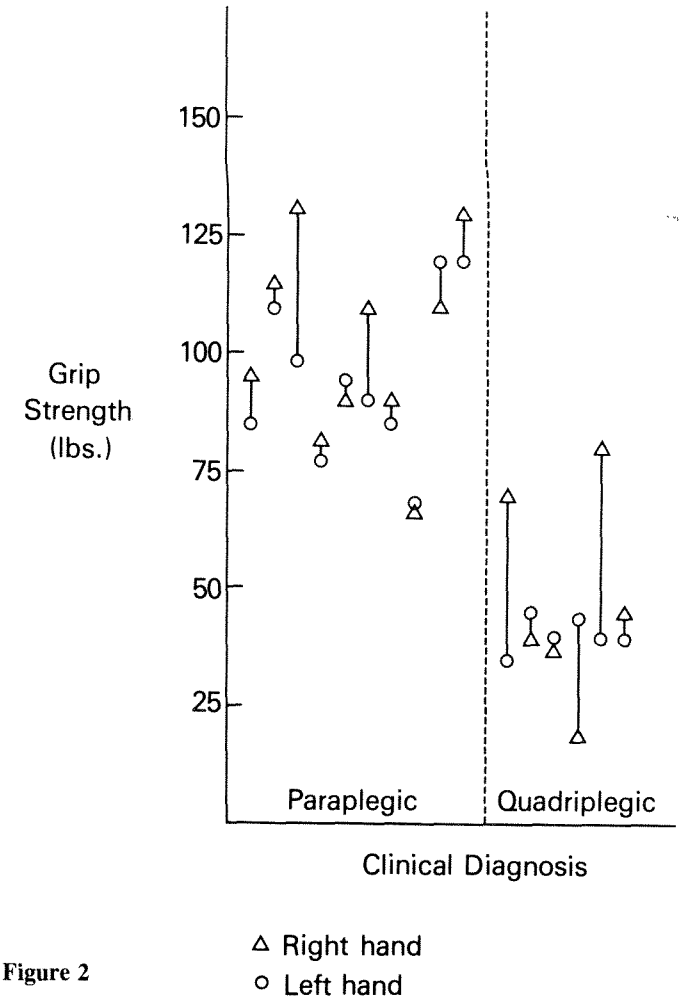

Figure 2

between $20 and $60. Sixteen of the 21 paraplegics (76 percent) said they would pay the lower estimate, although only 10 (48 percent) would pay the higher estimate.

The responses of the quadriplegic subjects were mixed. The numbers are not sufficient to establish a relationship between grip features and preference. However, the two quadriplegics with larger hands liked the test rims; whereas those with smaller hand grip size had mixed responses (**Figure 3**). Five of the seven (71 percent) of the quadriplegics said they would pay the lower add-on cost, though only two (29 percent) would pay the higher estimate.

DISCUSSION

This study indicates that a simple design improvement of the wheelchair handrim intended to improve the power transmission linkage would be well accepted among experienced wheelchair users. This was verified for the paraplegic user group in three separate kinds of questioning: comparison of the test rims to the users' handrims in specific situations and terrain and in general situations, and also estimation of value.

The paraplegics constitute the largest group of spinal cord injured wheelchair handrim users, since many higher quadriplegics need electric wheelchairs. Therefore, we were able to collect sufficient data from a large sample of paraplegic subjects and make a meaningful evaluation long before a comparable-sized group of quadriplegic manual wheelchair users could be assembled and studied. What is notable is that this user opinion oriented study would not be possible if the equipment were used by so small a population that statistical tests on questionnaires would be meaningless.

Among the problems described in previous attempts at evaluating equipment, two stand out (8). First, conclusions must often be based on information from small numbers of users. Second, designers' participation in the evaluation may introduce unnecessary bias. This study of a new wheelchair handrim design provides sufficient data to give statistically significant results, and does not include the designer (3) who submitted his prototypes to us for evaluation at our discretion.

The users' value assessments suggest that people would be willing to pay extra for the rims. An open question asking how much subjects might pay would have given us a better estimate of value than the questions we asked, which reflected designer-estimated add-on cost.

The major barrier to interpretation of the favorable results is the material difference between the smooth-finished wood test rims and the users' own metal rims. As expected, many additional comments were focused on this difference. The high frictional heating and the attractive appearance of the wood rims were observed by almost all the respondents.

As a consumer-oriented study, this stands in contrast to other equipment evaluations that compare performance against fixed standards. In studying the other important human-machine interface for wheelchair users, the seat cushion, researchers have assessed pressure transmitted at bony prominences and soft tissue weight-bearing areas of seating (4,5). In an effort to shift the major weight-bearing forces forward to the thighs, other seating investigators developed a generalized cushion design (9). Force transmission through assistive devices has been studied extensively in gait analysis laboratories to aid in the prescription of orthotics and prosthetics. A novel and fixed evaluation standard is described in a comparison of powered wheelchair recliner mechanisms. In this study,

the displacements of the users in relation to the chair are compared (10). The selection of a meaningful performance criterion is essential to the validity of all these studies.

As performance criteria for the handrims, Brubaker et al. have chosen torque and dynamic power generated by users with the different handrim shapes attached to a wheelchair ergometer. Their data were not published because the subject wore gloves whose contact surfaces were thought to have changed sufficiently during the testing to affect the torque and dynamic power measurements on their wheelchair ergometer. However, they suggest that larger area of contact permits better force transmission, but the key factor is the coefficient of friction of the handrim material (1). More contact friction permits better force transmission. Their results are consistent with ours, insofar as larger handrims were associated with better performance. However, the ergometric findings also illustrate the importance of the material used for the handrims and also provided experience in using wooden prototypes to test handrim shapes. Unfortunately, the sensible handrim cross-section design has not been accepted by wheelchair manufacturers.

The results of this study parallel the experience of a commercial handrim that was designed for maximum contact. In 1980, a molded plastic combination spoke cover and handrim called Strokers (Equalizer Corp., P.O. Box 1296, San Luis Obispo, CA 93401) was introduced commercially by a wheelchair producer. It met with little success because while several different molds were necessary to fit many variations in wheelchair handrim and wheel sizes, the material selected, ABS plastic, became too slippery for use in wet weather. The large grip surface of these rims was promoted in the manufacturer's product description and was well accepted by consumers (6).

This study explores users' opinions of proposed design improvement for wheelchair handrims. Obtaining sufficient numbers of responses to make statistical inferences has been possible because this design improvement can be used by many. Nevertheless, the product improvement has not been adopted by the wheelchair makers; perhaps the proprietary nature of the patent for the design has been a problem in allowing wheelchair users to enjoy the new development which can be widely used.

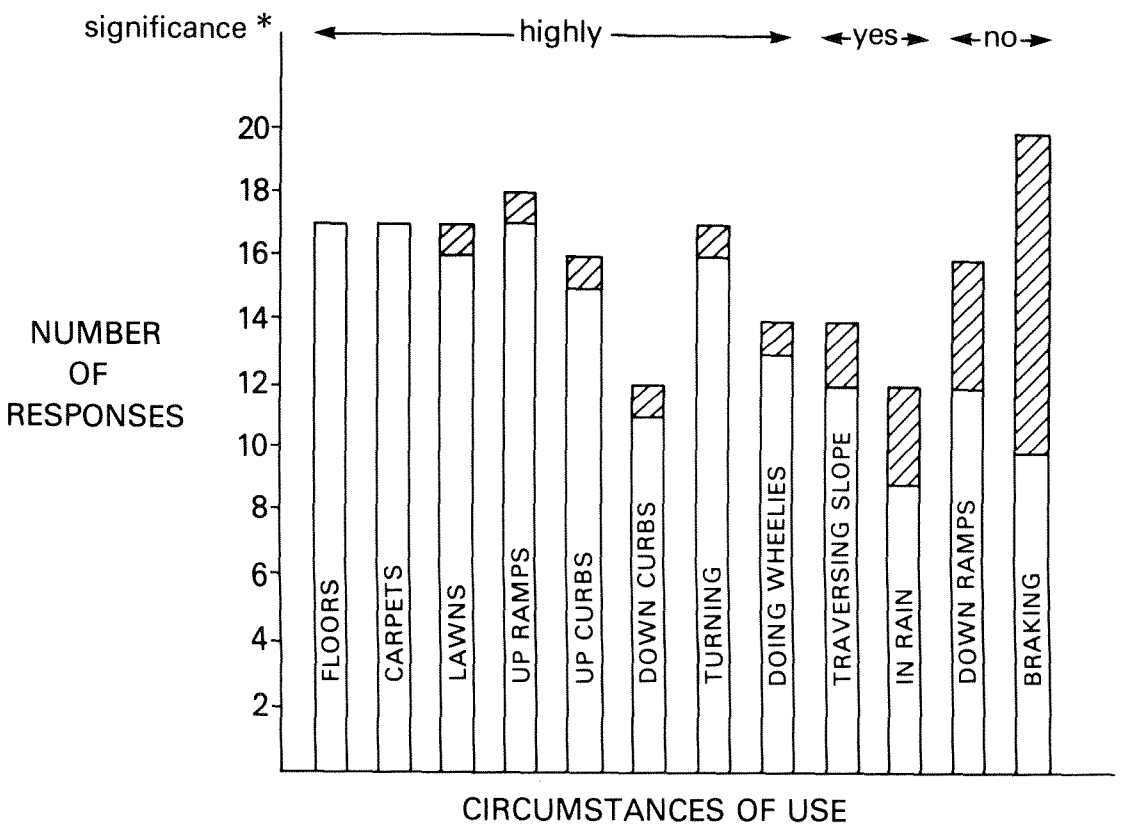

Figure 3

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