The Effects of Wheelchair Camber on Physiological and Perceptual Responses in Younger and Older Men

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This study examined the effects of 0, 4, and 8 degrees camber on the physiological and perceptual responses in younger (19-44 years) and older (45-74 years) sedentary, able-bodied men propelling a wheelchair at 2 kmh. Physiological and perceptual (rating of perceived exertion, RPE) responses were monitored using standardized procedures. Significant increases \( p < .05 \) in oxygen uptake, ventilation rate, and heart rate were observed with increasing camber angle. These values were not significantly \( p > .05 \) different between age groups. Central and peripheral RPE was unchanged as a result of camber angle in either group. Central RPE was significantly higher \( p < .05 \) for the older participants at a camber angle of 8 degrees. It was concluded that the physiological stress increases with camber angle during manual wheelchair propulsion at 2 kmh in younger and older men. The higher perceptual stress in older participants could be due to performance at a higher percentage of their maximum physiological capacity.

One of the primary goals in rehabilitation engineering is the design and development of wheelchairs that meet the needs of specific populations (Glaser, Simsen-Harold, & Petrofsky, 1983; Redford, 1993). This includes individuals with disabilities in wheelchairs and apparently healthy older individuals who lose the ability to ambulate independently. When designing wheelchairs, it is important to consider how mechanical factors influence the individual both physiologically and perceptually. It is likely that wheelchairs that minimize energy expenditure during propulsion will be the most functional. It has been theorized (Redford, 1993) that the higher the physiological cost, the more likely the individual is to become reliant on the caregiver for locomotion. In keeping with this notion, it seems reasonable to assume that a wheelchair design that conserves physiological energy will be perceived as less stressful and will lead to optimal functioning and increased independence. This will most likely transfer into a significant reduction in associated health-care costs.

One wheelchair design feature that has been minimally researched is rear wheel camber angle. Camber has been defined in several ways: "the angle of the..."
main wheel to the vertical” (Higgs, 1983), or the alignment of the rear wheels such that “the spacing between the top points of the wheels may be less than the spacing between the bottom points” (Frank & Abel, 1993). Because hand rim propulsion is the most common form of wheelchair propulsion, and rear wheel camber occurs directly at the equipment-user interface, it is imperative that the effects of camber be scientifically evaluated.

Increased rear wheel camber can result in greater mechanical efficiency (Brubaker & McLaurin, 1984) and stability (Higgs, 1983; Trudel, Kirby, & Bell, 1995). As well, increased camber can diminish the power output required to propel the wheelchair (Brubaker, McLaurin, & McClay, 1986). Scientific data pertaining to the effects of camber on the physiological responses during wheelchair propulsion are limited (Trudel et al., 1995; Veeger, van der Woude, & Rozendal, 1989). Veeger et al. (1989) observed no significant effect of 0, 3, 6, and 9 degrees camber on the physiological responses in young able-bodied participants propelling a wheelchair at 2 kmh. However, it should be noted that the researchers attempted to compensate for the concomitant changes in rolling resistance by adding loads to the wheelchair during propulsion. Because this modification does not occur in realistic settings, the generalizability of their findings is questionable. Currently, research pertaining to the effects of wheelchair camber in an older population is lacking. The purposes of this study therefore were to (a) examine the effects of rear wheel camber angle on the physiological and perceptual responses in younger and older men during manual wheelchair propulsion, and (b) compare these responses between the two age groups.

Method

Sample

Written informed consent was obtained from 19 apparently healthy, sedentary male volunteers for this study. Participants were nonwheelchair users who had no previous experience with wheelchair propulsion. Individuals were eligible to participate in the study if they (a) satisfactorily completed a Physical Activity Readiness Questionnaire (British Columbia Ministry of Health and the Department of National Health & Welfare, 1978), (b) completed a general activity questionnaire, and (c) were not currently involved in any strength or fitness training program. Participants were assigned to a younger group (n = 7) ranging in age from 19 to 44 years, or an older group (n = 12) ranging in age from 45 to 74 years. Participants were normally distributed in both age groups. The means and standard deviations for age, height, weight, and body surface area for the younger group were as follows: 25.4 ± 7.0 years, 166.8 ± 11.0 cm, 70.6 ± 18.7 kg, and 1.80 ± .30 m², respectively. Corresponding values for the older group were 59.1 ± 8.6 years, 174.2 ± 5.9 cm, 80.8 ± 6.2 kg, and 1.98 ± .09 m², respectively. The two groups were significantly different (p < .05) from each other for each of these characteristics.

Description of the Wheelchair Roller System

The customized roller system used in this study has been previously described (Bhambhani, Holland, Eriksson, & Steward, 1994). The wheelchair (Quickie GPS, Sunrise Medical) was mounted on a specially constructed, low friction steel roller system, having a circumference of 53 cm. An optical sensor was mounted on
the roller frame to detect signals from the roller each time a strip of reflective tape crossed its path. This information was then transposed to an analog/digital board in a computer, which was interfaced with the wheelchair roller system. The wheeling velocity and distance traveled were then calculated from the roller circumference and revolutions per minute using a customized computer program. The information was displayed visually as a speedometer on the computer monitor placed directly in front of the participant during propulsion. The roller system was calibrated prior to the commencement of the study using a Cateye odometer (Cateye Model cc ST300) and by simultaneously counting the wheel revolutions for independent verification.

Adjustment of Wheelchair Camber

The Quickie GPS wheelchair was selected for this study because of its adjustable camber angle bar system. This wheelchair, which weighed 9.3 kg, allowed for camber settings of 0, 4, and 8 degrees. In order to eliminate possible wheelchair biases, the same wheelchair was used for all the participants throughout the study. The interchangeable camber bars were designed to minimize the effects of “toe in/toe out” with changes in camber angle. Frank et al. (1991) have defined toe in/toe out as the condition where “the spacing between the front points of the left and right wheels may be unequal to the spacing between their rear points.” In this study, camber bars were placed to ensure that: (a) both right and left wheels were equidistant from the wheelchair at superior, anterior, and posterior points, and (b) the rear wheels were aligned with the circumferential tracking line of the ergometer. Alignment and measurement were performed by two trained technicians after each camber change.

Test Protocol

Each participant completed one testing session that lasted approximately 1 1/2 to 2 hr during which he completed three camber angle tests (0, 4, or 8 degrees) in random order. Rear wheel camber angle was adjusted as previously described, following which the participant was seated in the wheelchair. Seat height was recorded for each participant and remained constant relative to each person throughout the entire testing procedure and changes in camber angle. Baseline physiological responses were recorded for 4 min while the participant remained seated in the wheelchair. Thereafter, the participant completed a 5-min, free-wheeling familiarization period during which he was given instructions pertaining to the central (heart and lungs) and peripheral (related to the localized muscles) ratings of perceived exertion (RPE) on the Borg scale (Borg, 1982). The use of a familiarization period for wheelchair propulsion tasks has previously been demonstrated to be useful in controlling for unforeseen variables (Glaser et al., 1983; Masse, Lamontagne, & O’Riain, 1992). At the end of the familiarization period, participants rested for 8 min to allow the physiological responses to return to resting levels. Thereafter, the first of three camber testing sessions was initiated at a constant velocity of 2 kmh for a period of 8 min 30 s. After 8 min of propulsion had elapsed, the participant was asked to indicate his central and peripheral RPE. The three camber phases were interspersed with 8-min rest periods during which camber angles were adjusted and the wheelchair was remounted on the roller system. Physiological recovery was ascertained during this period by ensuring that the
oxygen uptake \((\text{VO}_2)\), heart rate (HR), and ventilation volume \((V_E)\) attained baseline values, as indicated by the metabolic cart.

**Cardiorespiratory Measurements**

An automated metabolic cart (Model 29002, Sensormedics Corporation, CA) was used to monitor the respiratory gas exchange measurements continuously during the test. The oxygen and carbon dioxide analyzers in the metabolic cart were calibrated prior to and after each test using commercially available precision gases (26% oxygen, balance nitrogen; and 16% oxygen, 4% carbon dioxide, balance nitrogen). The volume measured by the mixing chamber was calibrated by injecting 3 L of air from a syringe at two different flow rates, as recommended by the manufacturer. The instrument was programmed to display and print out real time data of the \(\text{VO}_2\), \(V_E\), and respiratory exchange ratio (RER) every 20 seconds of the test.

The HR was recorded using a wireless monitor (Model 3000, Sport Tester, Polar Key, Finland) that was strapped on to the participant’s chest. The reliability and accuracy of this instrument for recording HR during exercise has been previously demonstrated (Leger, 1988). The physiological responses were averaged during the last 2 min of steady state exercise and used for subsequent analysis.

From the absolute oxygen uptake \((\text{AVO}_2, \text{ml/min})\) data obtained from the metabolic cart, the following variables were calculated: (a) relative oxygen uptake per kilogram of body weight \((\text{RVO}_2, \text{ml/kg/min})\), (b) oxygen pulse \((\text{O}_2\text{pulse})\), calculated as the ratio between \(\text{AVO}_2\) and HR, (c) net energy cost (NEC, Cals/min), calculated as the product of the \(\text{AVO}_2\) and the kilocaloric equivalent using the non-protein RQ values given in Weir (1940). In order to calculate the NEC, the baseline \(\text{VO}_2\) was deducted from the \(\text{AVO}_2\) to obtain the actual \(\text{VO}_2\) for wheelchair propulsion. For each participant, the predicted maximum HR was calculated using Karvonen's formula, 220 – age in years (McArdle, Katch, & Katch, 1991). This value was used to calculate the percentage of predicted maximum HR achieved during each phase of the test protocol.

**Statistical Analysis**

Data were analyzed using a two-way (Age by Camber) repeated measures analysis of variance for each variable. Significant \(F\) ratios were analyzed using post hoc Scheffé tests. The level of significance for all tests was set at .05. A Bonferroni correction factor was applied to minimize the possibility of a Type I error (Ottenbacher, 1991). All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS).

**Results**

**Effects of Wheelchair Camber**

The physiological and perceptual responses during wheelchair propulsion at rest (i.e., baseline) and the three camber angles in the younger and older participants are summarized in Table 1. It is evident that there was a significant increase in the \(\text{VO}_2\) as
Table 1 Physiological and Perceptual Responses During Wheelchair Propulsion at 2 kmh in Younger and Older Men at Three Camber Angles

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Baseline</th>
<th>0 degrees</th>
<th>4 degrees</th>
<th>8 degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute oxygen uptake, ml</td>
<td>Young</td>
<td>265 ± 70</td>
<td>496 ± 126</td>
<td>525 ± 154</td>
<td>621 ± 274</td>
</tr>
<tr>
<td>Uptake, ml · min⁻¹</td>
<td>Old</td>
<td>277 ± 41</td>
<td>568 ± 61</td>
<td>570 ± 190</td>
<td>657 ± 80</td>
</tr>
<tr>
<td>Relative oxygen uptake, ml</td>
<td>Young</td>
<td>3.8 ± .5</td>
<td>7.1 ± .6</td>
<td>7.4 ± .5</td>
<td>8.6 ± 1.7</td>
</tr>
<tr>
<td>Uptake, ml · kg⁻¹ · min⁻¹</td>
<td>Old</td>
<td>3.5 ± .6</td>
<td>7.1 ± .8</td>
<td>7.1 ± .7</td>
<td>8.1 ± 0.9</td>
</tr>
<tr>
<td>Heart rate, beats · min⁻¹</td>
<td>Young</td>
<td>73 ± 20</td>
<td>87 ± 16</td>
<td>88 ± 16</td>
<td>92 ± 15</td>
</tr>
<tr>
<td>Beats · min⁻¹</td>
<td>Old</td>
<td>69 ± 8</td>
<td>86 ± 9</td>
<td>87 ± 8</td>
<td>91 ± 10</td>
</tr>
<tr>
<td>Ventilation volume, L · min⁻¹</td>
<td>Young</td>
<td>8.3 ± 2.5</td>
<td>15.4 ± 2.5</td>
<td>16.2 ± 3.7</td>
<td>18.8 ± 6.0</td>
</tr>
<tr>
<td>Relative oxygen uptake, ml</td>
<td>Old</td>
<td>10.3 ± 2.2</td>
<td>20.7 ± 3.0</td>
<td>20.3 ± 3.8</td>
<td>24.2 ± 5.3</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>Young</td>
<td>.82 ± .06</td>
<td>.88 ± .05</td>
<td>.88 ± .03</td>
<td>.91 ± .05</td>
</tr>
<tr>
<td>Exchange ratio</td>
<td>Old</td>
<td>.85 ± .07</td>
<td>.89 ± .05</td>
<td>.90 ± .03</td>
<td>.91 ± .05</td>
</tr>
<tr>
<td>Oxygen pulse, ml</td>
<td>Young</td>
<td>3.9 ± 1.6</td>
<td>6.0 ± 2.3</td>
<td>6.3 ± 1.2</td>
<td>7.0 ± 3.4</td>
</tr>
<tr>
<td>ml · beat⁻¹</td>
<td>Old</td>
<td>4.0 ± 0.6</td>
<td>6.6 ± 0.6</td>
<td>6.5 ± 1.2</td>
<td>7.3 ± 0.9</td>
</tr>
<tr>
<td>V̇E/VO₂ ratio</td>
<td>Young</td>
<td>31.2 ± 2.9</td>
<td>31.7 ± 4.1</td>
<td>31.6 ± 4.7</td>
<td>31.4 ± 4.7</td>
</tr>
<tr>
<td></td>
<td>Old</td>
<td>37.4 ± 6.5</td>
<td>36.8 ± 7.1</td>
<td>36.5 ± 6.9</td>
<td>37.0 ± 7.8</td>
</tr>
<tr>
<td>Net energy cost</td>
<td>Young</td>
<td>—</td>
<td>16.4 ± 2.0</td>
<td>18.1 ± 2.9</td>
<td>24.2 ± 8.1</td>
</tr>
<tr>
<td>Cals · kg⁻¹ · min⁻¹</td>
<td>Old</td>
<td>—</td>
<td>17.9 ± 3.0</td>
<td>17.6 ± 5.7</td>
<td>23.4 ± 5.2</td>
</tr>
<tr>
<td>Central perceived exertion</td>
<td>Young</td>
<td>—</td>
<td>7.6 ± 1.0</td>
<td>8.0 ± 1.5</td>
<td>8.4 ± 1.9</td>
</tr>
<tr>
<td>Exertion</td>
<td>Old</td>
<td>—</td>
<td>9.3 ± 1.2</td>
<td>10.1 ± 1.8</td>
<td>9.7 ± 1.5</td>
</tr>
<tr>
<td>Peripheral</td>
<td>Young</td>
<td>—</td>
<td>8.9 ± 1.2</td>
<td>9.3 ± 1.3</td>
<td>10.3 ± 1.3</td>
</tr>
<tr>
<td>Perceived exertion</td>
<td>Old</td>
<td>—</td>
<td>10.0 ± 2.0</td>
<td>10.5 ± 2.3</td>
<td>10.3 ± 2.4</td>
</tr>
</tbody>
</table>

*Indicates significant differences (p < .05) between 8 degrees camber compared to 0 and 4 degrees camber.

bIndicates significant differences (p < .05) between 0 and 4 degrees camber.

cIndicates significant differences (p < .05) between younger and older age groups.

The camber angle increased from 0 degrees to 8 degrees in the younger and older participants. This was true whether the values were expressed in absolute terms, or if body weight was factored into the analysis. These increases in VO₂ were accompanied by significant increases in HR, V̇ E, and O₂ pulse in both the age groups. However, despite the significant increases in these physiological variables, no significant changes were observed in the central and peripheral RPE with camber angle in either age group. Generally speaking, participants perceived the wheelchair propulsion task to be in the “very light” to “light” range according to the verbal descriptors on the Borg scale. There was a tendency for the peripheral RPE to be higher than the central RPE at each camber angle, but these differences were not significant.

The net energy cost, which was calculated after deducting the baseline oxygen uptake values, showed a significant increase as a result of increasing camber in both groups. The overall increase from 0 to 8 degrees camber was approximately 48% in the younger group and 31% in the older group.
Differences Between Age Groups

As indicated in Table 1, there was no significant difference between the younger and older participants at rest (baseline) and during wheelchair propulsion at the three camber angles for $AVO_2$, $RVO_2$, HR, RER, and $O_2$ pulse. There was a tendency for $AVO_2$ to be consistently higher in the older participants at all three camber angles, but the differences were negated when body weight was factored into the calculations. The $V_{E}$ and $V_{E}/VO_2$ ratio (an index of the economy of ventilation) were significantly higher in the older participants compared to the younger ones. Central RPE was significantly higher in the older participants than the younger ones at 0 and 4 degrees camber, but not at 8 degrees. No significant differences were observed between the age groups for the peripheral RPE at the three camber angles.

Discussion

Comparison With Previous Studies

In this study, mean $AVO_2$ ranged from .50 L/min ($\pm .13$) in the younger group to .66 L/min ($\pm .08$) in the older group. These values were similar to those reported by Glaser et al. (1983), who obtained a value of .53 L/min at a similar velocity in wheelchair users and non-users, but slightly lower than those of Veeger et al. (1989), who reported an $AVO_2$ of approximately .70 L/min in males performing variable camber wheelchair exercise at a velocity of 2 kmh. In addition, the HR of 86 $\pm$ 9 to 91 $\pm$ 10 beats/min and $V_{E}$ of 15.4 $\pm$ 2.5 to 24.2 $\pm$ 5.3 L/min are comparable to those previously reported (Glaser et al., 1983; van der Woude, Hendrich et al., 1988; van der Woude, Veeger et al., 1988) for this exercise mode and intensity.

Effects of Wheelchair Camber Angle

It has been suggested (Brubaker et al., 1984; Higgs, 1983; Veeger et al., 1992) that increased rear wheel camber leads to a greater mechanical advantage during wheelchair propulsion because of the increased proximity of the rear wheel to the wheelchair frame. It is therefore reasonable to hypothesize that the physiological stress would be significantly reduced as camber angle increases. However, the results of this study did not support this hypothesis. Rather, the evidence suggested the opposite, that increased camber angle increased the physiological stress at a propulsion velocity of 2 kmh in both younger and older participants. The overall increase in NEC was considerably high: 48% in the younger group and 31% in the older group. It is interesting to note that, although Veeger et al. (1989) suggested that increased camber angle would improve the mechanical efficiency during wheelchair propulsion, this was not supported by their physiological data which demonstrated no significant changes with wheelchair camber.

In this study, although the energy cost of wheelchair propulsion increased with camber angle, this was not accompanied by any increase in the perceptual stress, central or peripheral, in either age group. Previous studies have established the validity of the Borg RPE scale (Borg & Noble, 1974; Goslin & Rorke, 1986; Pandolph, 1983) against physiological responses such as $VO_2$, HR, and $V_{E}$ during cycle exercise. However, the present data suggest that, at low intensities of wheel-
Wheelchair Camber in Younger and Older Men

chair exercise performed by healthy participants, there seems to be a dissociation between the physiological and perceptual responses.

Comparison Between Younger and Older Participants

The current findings indicated no significant differences between the younger and older participants for the NEC and HR measurements at any of the wheelchair camber angles studied. The values obtained for both these groups were similar and did not reveal any trend in the responses. Although no significant differences were observed between the two age groups for the central and peripheral RPE responses at each of the camber angles, there was a tendency for the older participants to demonstrate higher RPE values. This is most likely due to the fact that the relative physiological stress was higher in the older participants (i.e., they were exercising at a higher percentage of their peak physiological capacity). The peak physiological responses were not directly measured in this study, but it is generally accepted that maximal aerobic power (VO₂max) and maximal HR decline with age (deVries, 1989). During lower body exercise, such as cycling, the decrease in absolute VO₂ is estimated at approximately 10% per decade beyond the age of 20 years. Assuming a similar rate of decline during wheelchair exercise for the 35-year mean age difference between the two groups in this study, it is likely that there was a 35% difference in the VO₂max of the participants.

According to the Karvonen formula (McArdle et al., 1991), the maximal HR is inversely related to the individual’s age (220 – age, yrs). As can be seen in Table 2, the younger participants in this study were exercising at approximately 45% of their predicted maximal HR (195 bpm), while the older participants were exercising at approximately 55% of the predicted maximal HR (161 bpm) for each of the three camber angles. These values were significantly different between the two groups for each of the camber angles evaluated. Hence, the trend for the higher central perceptual stress in the older participants was most likely due to the fact that they were exercising at a higher percentage of their VO₂max and maximal HR than the younger participants.

Sawka et al. (1981) reported that to perform a specific locomotive task, such as wheelchair propulsion at a given velocity, a specific power output must be achieved by the individual. The closer that the power output requirements come to the maximal power output that the individual can generate, the more difficult the task becomes. In this study, power output during wheelchair propulsion was not quantified because of limitations with the roller system used for testing. However,

<table>
<thead>
<tr>
<th>Group</th>
<th>0 Degrees</th>
<th>4 Degrees</th>
<th>8 Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young*</td>
<td>44.6 ± 7.0</td>
<td>45.2 ± 7.1</td>
<td>47.4 ± 6.4</td>
</tr>
<tr>
<td>Old</td>
<td>53.8 ± 6.5</td>
<td>54.1 ± 5.0</td>
<td>56.5 ± 7.0</td>
</tr>
</tbody>
</table>

*Indicates significant difference between groups for each camber angle.
it is well-accepted that maximum muscular strength, which could influence the ability to generate power, also declines with age (McArdle et al., 1991). Hence, the older participants were most likely exercising at a higher percentage of the maximal power output, which would account for the trend toward higher peripheral RPE values observed in this group.

**Limitations of the Study**

Wheelchair propulsion studies on aging, sedentary populations are scarce. However, before the findings of the present study can be generalized to the aging population, its limitations need to be identified. These include: (a) selection of the wheelchair propulsion velocity, (b) use of able-bodied participants, and (c) changes in rolling resistance with camber angle.

The use of constant velocity as opposed to self-selected velocity continues to be controversial in studies of this type. Because the purpose of the current study was to examine the impact of camber angle on an aging, sedentary population using wheelchairs for daily living tasks, it was important that the propulsion velocity selected was comparable to that used in daily living tasks. Previous research (Hjeltnes & Vokac, 1979; Janssen, Oers, Hollander, van der Woude, & Rozendal, 1992; Veeger et al., 1989) has demonstrated that a propulsion speed of 2 kmh is common to many wheelchair propulsion activities. Hence, a constant velocity test of 2 kmh was selected in this study. However, caution should be exercised in extrapolating the results of this study to speeds other than 2 kmh, which may be experienced in some activities of daily living (Hutzler 1993; Jochheim & Strokendl, 1973), and to populations that are not sedentary. As well, the evaluation of nonwheelchair users in the current study, who may not be representative of wheelchair ambulatory individuals, poses a severe limitation of these findings.

It is generally accepted that an increase in camber results in a concomitant increase in rolling resistance. It has been reported (O’Reagan, Thacker, Kauzlarich, Mochel, Carmine, & Bryant, 1981) that a change of 10 degrees in camber angle will likely increase the rolling resistance by less than 5%. In this study, no compensation was made for maintaining rolling resistance with increasing camber angle as was done by Veeger et al (1989). Because the highest camber angle used in the present study was 8 degrees, it is believed that the increase in rolling resistance was negligible. Hence, the increase in physiological stress observed in this study was most likely due to changes in camber angle.

**Clinical Implications**

A large majority of wheelchair users are older individuals who have sedentary lifestyles. Moreover, these individuals tend to have significant cardiovascular problems, which have a major impact on their physical abilities. Thus, it is important that wheelchairs that minimize the cardiovascular stress be prescribed to these individuals for activities of daily living. While some individuals may benefit from an increased demand on the cardiorespiratory system, primarily through improved fitness and a reduction in the risks associated with inactivity, others may experience undue discomfort and further medical complications consequent to the increased physiological burden.

It has long been a common assumption among clinicians that increased rear wheel camber will result in greater ease of wheelchair propulsion. However, the current findings suggest that this assumption needs to be reconsidered. While in-
creased rear wheel camber adds stability to the wheelchair (Brubaker et al., 1986; Higgs, 1983; Sanderson & Sommer, 1985), careful consideration must be given to whether the advantage gained through greater stability is worth the increased energy cost demonstrated in this study. In keeping with this notion, the greater physiological demand imposed by increased camber angle could potentially result in the older individual being unable to propel the wheelchair for extended periods. It has previously been suggested (Redford, 1993) that wheelchairs that require the least amount of energy will lead to the greatest usage and maximal independence. Viewed in these terms, it is reasonable to conclude that a wheelchair that is physiologically economical and increases the independence of the individual will ultimately result in less burden on caregivers for locomotive purposes. This could represent substantial savings in health care expenditures.

References


Author Notes

The assistance of Sunrise Medical, Calgary, Alberta, for the loan of the Quickie GPS wheelchair is gratefully acknowledged.