ABSTRACT

Objective: The goal of this study was to determine how the Segway compares to clients’ current method of mobility in meeting their specific mobility goals.

Design: This study included 10 subjects (aged 19–65 yrs) with a wide range of disabilities (e.g., multiple sclerosis, spinal cord injury, and amputee) who were able to walk at least 6 m with or without assistance. Subjects navigated a 25-m obstacle course at our provincial adult rehabilitation center with their current mobility devices and then the Segway. The outcome measures used were the Wheelchair Outcome Measure score and the difference in the time required to complete the obstacle course.

Results: There was a significant difference in Wheelchair Outcome Measure score between subjects’ current mobility method and using the Segway for client specific goals ($P < 0.01$); however, there was no significant difference between obstacle course times.

Conclusions: This study has shown that the Segway may be a good device for people with disabilities because it allows them to participate in social and functional activities in a manner that traditional mobility aids do not facilitate as well. However, it does have its limitations and should be considered as just one of the many mobility options offered to people with disabilities.

Key Words: Disability, Mobility, Assistive Technology, Dependent Ambulation, Segway
Since the World Health Organization developed the International Classification of Functioning, Disability and Health model for assessing people who have mobility impairments, therapists have been given an even greater mandate to consider all aspects of improving a person’s functional level from multiple perspectives. This means more than just finding a device to get a person from point A to point B. It also includes how the device addresses one’s ability to fully participate in activities and meets other issues related to functional goals, such as self-esteem and satisfaction. Also, the line between devices that were acceptable for the able-bodied population vs. the disabled is now less defined, so when something like the Segway is targeted for the able-bodied market, what do therapists do when their clients ask if the therapist will recommend a Segway over a scooter? What evidence is there for the therapist to base this decision?

Individuals with mobility impairments may experience limitations to their ambulation, including fatigue, distance, speed, and the type of terrain they are able to negotiate. Stigmatization is often associated with using a mobility device, along with subsequent psychosocial consequences. Individuals with mobility impairments often use a wheeled device to achieve their mobility goals. People with sufficient lower- or upper-limb strength and coordination commonly use a cane, walker, or manual wheelchair, whereas those who lack the physical strength to propel manually will use a power wheelchair or scooter. Although wheelchairs, scooters, canes, and walkers are valuable assistive mobility devices, getting around the community for purposes such as shopping, socializing, recreation, and working can still be a challenge. Each device has its own set of limitations, presenting functional challenges to the person with the mobility impairment. Many environments are still not accessible when a person uses a wheeled mobility device (e.g., stairs, uneven terrain, or high shelves). Consequently, when considering the appropriate wheeled mobility device, performance trade-offs are numerous and must be considered on an individual basis.

The Segway Personal Transporter is an addition to conventional mobility devices, such as wheelchairs, walkers, and scooters. It is a self-balancing, electric-powered transportation device. The rider stands on a small platform held 20 cm off the ground by two parallel wheels and holds onto handlebars. The Segway model i167 used for this study has the steering mechanism mounted on the left handlebar that one twists to go either left or right. The Segway balances itself using solid-state gyroscopes and sensors that constantly sense an individual’s center of gravity and make minute adjustments to ensure a balanced and upright position. When the rider leans forward, the Segway moves forward to maintain an upright position. When the rider leans back, the Segway stops and then moves in reverse.

The Segway has already been used by the Canadian and United States Postal Services, Chicago Police, Boston Emergency Medical Services, and local university and airport security; however, it has not been openly marketed to people with mobility impairments, nor has the device gained much acceptance from professionals as a mobility device suitable for people with disabilities. It is not approved by the U.S. Food and Drug Administration as a medical device. Unfortunately, this means that its purchase is not covered by most insurance companies, even though it can be much less expensive than many power wheelchairs. Nevertheless, a number of people with disabilities have seen the potential this technology offers to improve their mobility and have purchased their own devices and shared their experiences via the internet. However, there is a paucity of peer-reviewed literature concerning the use of the Segway for people with mobility impairments.

For therapists, selecting the right mobility aid for someone requires individualized assessments to match the needs, abilities, and goals of the client with the properties of the device. In general, most assistive devices are well researched and clinically assessed to meet the needs of a targeted disability group. A pilot study has shown that participants with a wide range of neurologic conditions and physical abilities are able to safely and effectively operate Segway i167. Aside from this study, there has been no published work comparing the Segway with more traditional mobility devices used by people with disabilities. Thus, the goal was to determine how the Segway compares to clients’ current methods for mobility at meeting specific mobility goals.

**METHODS**

**Participants**

Ten participants were randomly selected from a previous study population of 24 participants with a variety of disabilities. The inclusion criteria were adults aged 19–65 yrs who were able to follow verbal English instructions, were able to walk 6 m with or without assistive devices, and had a functional impairment requiring them to use an assistive device for mobility. All participants in the current project were recruited because they had successfully completed three Segway training sessions (phase I) and were considered safe and competent on the Segway. The project was approved by the local university and hospital clinical research ethics boards.
All individuals in the previous pilot project had expressed interest in future studies regarding the Segway; thus, we randomly selected 10 subjects from phase I to participate in phase II of the study. Subjects were sent a letter inviting them to participate and were asked to contact the study coordinator if they were interested in participating. Three subjects declined phase II of the study because of personal illness and challenges, thus three additional randomized subjects were invited to participate and agreed.

**Outcome Measures**

**Wheelchair Outcome Measure (WhOM)**

The WhOM is a 20- to 30-min, semistructured interview that assesses the wheelchair users’ participation in activities both inside and outside their home.\(^\text{11}\) It is understood that the WhOM was designed for assessing primarily wheelchairs; however, the authors considered the WhOM to be the best measure available for the purposes of this study. It is a measure of participants’ satisfaction with their wheelchair or mobility device toward how well it met their mobility goals. Participants identified activities they currently do or want to participate in using their wheelchairs (e.g., going to the park, shopping, or keeping pace with peers) and ranked the importance of these activities plus their satisfaction of how well they can perform these activities both on a scale of 0–10, with 10 being totally satisfied and 0 totally dissatisfied. The scores of importance and satisfaction were then multiplied. The total score is the sum of the multiplied values. Results can be analyzed based on a single item or the total scores. The reliability of the WhOM has been established with an interrater intraclass correlation of 0.91 and a test-retest intraclass correlation of 0.93. For content validity, the WhOM was shown to be positively correlated with the Quebec User Evaluation of Satisfaction with Assistive Technology instrument (\(r = 0.583\)), another satisfaction measure, and the mobility categories of the Assessment of Life Habits (e.g., entering/exiting home; \(r = 0.330\)).\(^\text{12}\)

**Time to Complete Indoor Obstacle Course**

To provide us with an objective measure of comparison between the two methods of mobility, we chose an agility course (approximately 25 m long) that was designed to represent common obstacles encountered by manual wheelchair users in daily community living.\(^\text{13}\) It consisted of eight obstacles (e.g., speed bumps, carpet, rumble strip, and curb drop) fixed solidly to a flat gymnasium floor that had been used in previous wheelchair research to assess functional issues related to wheelchair mobility (Fig. 1).\(^\text{13–15}\) Participants were given some time to become familiar with the course both with their current mobility and Segway before testing. The subjects were asked to negotiate the course safely, at their comfortable pace, using their current mobility aid. This task was timed with a stopwatch, and a physiotherapist spotted the participant through the task to ensure optimal safety. After a short rest, the participant negotiated the indoor course using the Segway.

**Protocol**

Participants came to the local rehabilitation center for one visit, which lasted approximately 2 hrs. On arrival, the study was described to the subject again, and consent was obtained. After consent was given, the primary investigator (B. Sawatzky) administered the WhOM questionnaire, based on their experiences of their current method of mobility. After the questionnaires, the participants negotiated the obstacle course using both their current mobility aid and the Segway. This was timed.

Using the participants’ mobility goals as recorded on the WhOM, the investigator (I. Denison) then simulated a participant-specific outdoor course. This course reflected the environmental obstacles that the participant indicated they needed to overcome to successfully attain their identified goals. For example, one participant wanted to “walk” to the local shopping plaza four blocks from home to purchase small items and meet a friend for coffee. This participant would use the Segway to simulate going to the local shops a few blocks away, negotiating similar terrain he would typically contend with, and go in the shops, getting on and off the Segway to simulate stopping for coffee. Another participant wanted to go for walks with his spouse along park trails not far from home, which he cannot do with crutches. We then took this participant using the Segway to the park to negotiate various rougher terrain areas.

Participants negotiated their tailored course using the Segway, supervised by two investigators (I. Denison and A. Tawashy). Subjects spent as much time on each section as they needed to form an
educated opinion of how well the Segway would help them achieve their community mobility goals. After this session, the participant completed the WhOM for the Segway. This was not a timed event but rather used only to give the participants a tool for completing the WhOM with respect to using a Segway.

Analysis

Paired t tests were computed for both outcome measures with a P value set a priori <0.01. Results from both the indoor obstacle course task and the WhOM assessment for the participants’ current method of mobility and the Segway were compared. To put the goals into a broader context of “function,” the authors chose to break down the goals into the three International Classification of Functioning, Disability and Health categories: Body Function and Structure, Activity and Participation, and Environmental Barriers (Facilitators). Some subjects had two goals, whereas others had more. For consistency, we chose to average the top three goals for all subjects. Because all the top two goals were rated 10 for importance, we only used the satisfaction score (0–10) for analysis. Two subjects had only two goals.

RESULTS

The demographics of the ten individuals participating in this study are described in Table 1. Most of the participants were men and had been diagnosed with multiple sclerosis or had sustained a spinal cord injury. The average time since diagnosis or injury was 12.4 yrs (range, 2–32 yrs). One subject used a powered mobility device, one used a manual wheelchair, and the remaining eight were ambulatory (with or without assistance). Only the device that was primarily used for daily mobility needs was recorded. Two subjects who had spinal cord injuries “brace walked” with long leg braces and crutches.

Wheelchair Outcome Measure

Using the WhOM, subjects identified 28 separate goals as being important to their quality of life. With respect to the International Classification of Functioning, Disability and Health categories, most of the goals fell under the Activity and Participation category. This included goals such as shopping, going for walks with wife/son, and hiking. The goals that fell into the Body and Function category were about therapeutic standing. Issues related to going over rough terrain and up hills were categorized under Environmental Barriers. Average WhOM scores obtained with the Segway were significantly greater than those obtained with the individual’s current mobility method (P < 0.01; power >0.9) in all three categories (Table 2).

Indoor Obstacle Course

On average, the participants completed the indoor obstacle course 8.30 (±23.45) secs faster using the Segway than they did using their current mobility aid. However, this result was not statistically significant. Three participants who normally ambulated with a cane or walker (subjects 1, 4, and

<table>
<thead>
<tr>
<th>Participant No.</th>
<th>Age</th>
<th>Sex</th>
<th>Condition</th>
<th>Length of Disability, yrs</th>
<th>Mobility Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>M</td>
<td>Incomplete SCI</td>
<td>2</td>
<td>Crutches</td>
</tr>
<tr>
<td>2</td>
<td>44</td>
<td>M</td>
<td>MS</td>
<td>7</td>
<td>Scooter</td>
</tr>
<tr>
<td>3</td>
<td>63</td>
<td>F</td>
<td>Incomplete SCI</td>
<td>24</td>
<td>Cane</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>M</td>
<td>Incomplete SCI</td>
<td>4</td>
<td>Walker</td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td>M</td>
<td>MS</td>
<td>15</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>39</td>
<td>M</td>
<td>Complete SCI</td>
<td>4</td>
<td>Wheelchair</td>
</tr>
<tr>
<td>7</td>
<td>54</td>
<td>M</td>
<td>Double leg amputation BK and AK</td>
<td>4</td>
<td>Prosthesis</td>
</tr>
<tr>
<td>8</td>
<td>55</td>
<td>M</td>
<td>Complete SCI</td>
<td>32</td>
<td>KAFO’s and crutches</td>
</tr>
<tr>
<td>9</td>
<td>51</td>
<td>M</td>
<td>MS</td>
<td>19</td>
<td>Cane</td>
</tr>
<tr>
<td>10</td>
<td>54</td>
<td>M</td>
<td>MS</td>
<td>13</td>
<td>Cane/nothing</td>
</tr>
</tbody>
</table>

SCI, spinal cord injury; MS, multiple sclerosis.

<table>
<thead>
<tr>
<th>Table 2 Mean WhOM scores for current vs. Segway mobility using ICF categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body/Function (n = 3)</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Segway</td>
</tr>
</tbody>
</table>

WhOM, Wheelchair Outcome Measure; ICF, International Classification of Functioning, Disability and Health.
9) were markedly quicker on the Segway than they were using their current mobility aid (>35 secs faster). Using the Segway, six participants were within 5 secs of their time using their current mobility aid (Fig. 2).

DISCUSSION

Based on the results of this study, the Segway addressed the needs of participants in all three areas of function as outlined in the International Classification of Functioning, Disability and Health; however, the greatest number of goals fell into Activity and Participation. This highlights its potential use for people with disabilities to enhance their participation. Mobility options are important to both able-bodied and disabled individuals in today's society. Both groups identify their mobility or recreational needs and will acquire the appropriate devices, except that people with disabilities often have more critical mobility needs with less available options. This is likely because of funding challenges and limited exposure of mobility options. Disabled individuals often are provided with one mobility aid that they are expected to use for all aspects of daily life (e.g., work, recreation, and physical activity). This can be limiting because a single mobility device may not satisfactorily meet all mobility goals. This contradicts the findings by Hoenig et al., which showed that people with disabilities require and prefer to have a selection of multiple mobility devices depending on the “life space” they are in to optimize function and satisfaction.

Conventional solutions to impaired mobility include canes, crutches, walkers, manual wheelchairs, scooters, and power chairs. The first three options are simple, low cost, and low tech solutions for individuals who have an increased energy cost of walking because of ataxia and/or weakness. They also play a large role in fall prevention. Although these devices are useful, they require that the individuals possess the physical capacity to ambulate. Considering that some individuals using assistive devices suffer from degenerative diseases (such as multiple sclerosis), it must be expected that some of these individuals will ultimately lose their ability to walk. Consequently, crutches, canes, and walkers may have a valuable but limited use for these individuals for the long term.

The Segway offers certain advantages over traditional wheelchairs and scooters. Manual wheelchairs are now seen to cause significant overuse injuries from wheeling and other wheelchair-related injuries (i.e., falls), which pose new problems for the disabled. It has been demonstrated that approximately 50% of manual wheelchair users with a spinal cord injury will ultimately develop repetitive strain injuries in the wrist, elbow, or shoulder. Also, the loss of standing posture causes hypercalciuria, severe osteoporosis, increased fracture risk, and joint contractions that can limit functional tasks like dressing and transferring. Thus, the Segway may be able to address issues related to Body and Function by encouraging standing and stimulating proprioception and balance. Subjects who had difficulties with balance...
and coordination because of multiple sclerosis found that the Segway compensated for this, making them feel less precarious and unsteady than when they walked.

The Segway is unusual in that it offers power mobility in a standing position. It does not require significant energy expenditure or upper-limb strength. In fact, most of the participants in the current study commented that they were able to use the Segway for longer periods than they were able to typically stand. Consistent use of the Segway could also increase this stamina over time. Also, one subject with incomplete tetraplegia had significant tone in his right hand, making it difficult to open and grab the Segway handgrip, initially. After 25 mins on the Segway, he could open and close his hand freely.

From an efficiency standpoint, participants negotiated the short indoor obstacle course with the Segway in comparable time to their current mobility aid and in three cases much faster. For the subjects who were faster with their current mobility devices, it may be owing to the fact that they had relatively limited time with the Segway. They were likely much more familiar with their current daily method of mobility. Consequently, it is possible that, with some practice, participants’ handling ability of the Segway potentially could improve further, thus showing a greater magnitude of change on the obstacle course. Although it would have been ideal to give the Segway to the participants for an extended period of time (i.e., 2 wks) before assessment of performance on the obstacle course, this was not feasible because of safety and ethical precautions. The results clearly indicate that the Segway has the potential to address environmental factors for people with disabilities.

Results from the WhOM indicated that the Segway may increase participants’ satisfaction in their ability to meet daily goals. These included, but were not limited to, activities such as walking children to school, accessing coffee shops and shopping malls, and “running” or going for walks with spouses. Using the Segway, participants were better able to contend with uneven terrain and cover ground efficiently (i.e., move faster and travel for longer periods of time). Furthermore, three participants noted that they would consider using the Segway for therapeutic purposes, such as standing, improving balance, and reducing spasticity.

Furthermore, in addition to the obvious mobility benefits it has to offer, the psychosocial benefits the participants gained from the Segway were clear. All participants commented that they felt less disabled when riding the Segway around the rehabilitation center. One subject reported being spoken to while out in public for the first time. Others commented on feeling a fluidity of movement that had been previously absent from their lives. Many participants noted that they were able to look around them as they moved at reasonable speeds, rather than looking down, constantly scanning for hazards.

One of the challenges with this study was that the company has changed its design since this study first began. This study used the Segway 167i, which is an older model, whereas the newer models use a LeanSteer mechanism for steering. To turn left or right, the rider simply moves the LeanSteer frame left or right. This new device has benefits and drawbacks. The LeanSteer mechanism eliminates the need for upper-limb manual dexterity. However, it does not offer the stabilization that the fixed frame does. For individuals with poor balance and trunk control, the first generation model may be more appropriate. The results of this study only apply to the earlier models that are still available in the market but in a limited supply.

**Limitations**

This study explored how the Segway could meet individuals’ mobility goals. By achieving their mobility goals, individuals may have the potential to increase their quality of life through increasing personal mobility. As such, outcome measures that assessed mobility as it related to quality of life were chosen. The WhOM is a measure that has been shown to be both reliable and valid and that can capture information about participation in life activities after an intervention. Thus, the WhOM was used in the current study to measure individuals’ mobility goals and their satisfaction of attaining these goals using both their current mobility aid and the Segway; however, the WhOM is a relatively new tool and has not been validated outside of wheelchair use or the spinal cord injury population. In our study, we also included those with multiple sclerosis and amputation.

In addition, participants’ scores on the WhOM and indoor obstacle course may not have reflected the potential magnitude of change, which may have occurred had the participants been permitted to use the Segway for a longer period of time and at home in their own environment. Because of safety precautions and practicality, this extended use was not possible. Providing this device for a longer period of time may also have shown that the positive findings in our study were the result of a novelty effect. Fatigue is still a significant factor because standing tolerance is essential for use of the Segway. We did not have subjects on the Segway longer than 30 mins at any one time. Subjects may find that over an extended period of time, they might prefer a seated system. These issues could be topics of future study given the groundwork provided by these initial studies, which show the ability levels of operating a Segway and the relative risks.

Another limitation in this study is the fact that there may be a sampling bias because participants originally self-selected themselves for phase I and II of this study. Although it was attempted to re-
duce the bias in phase II by randomly recruiting subjects from phase I, the favorable response on the WhOM may be overinflated because our original subject pool was highly motivated. However, it was important in this study to include those who had shown competence in using a Segway.

Furthermore, only one subject used powered mobility on a daily basis before the study. Thus, the favorable results from the Segway may be, in part, the result of the novelty of power mobility in general, rather than the specific aspects of the Segway. Additional research using multiple powered options for those who walk or use manual mobility aids would be necessary to better understand the limits of this study. Finally, the sample used in this study was small. Further research with a larger sample size must be conducted to generalize the results to the larger population.

CONCLUSIONS

Canes and crutches have been in clinical use for hundreds of years, and power wheelchairs and scooters have been used since the 1950s; the Segway is an intriguing new option that has potential benefits worthy of further investigation. With this type of evidence in peer review literature, funding for the Segway as a mobility device for people with disabilities might become a viable option.

The authors recognize that the Segway has inherent limitations that other previous mobility devices do not have. Also, the Segway is not yet considered a mobility device for people with disabilities; acceptance in the general public areas is still a potential problem in some jurisdictions. However, laws are constantly changing in favor of the Segway for people with disabilities. The Segway has a set of characteristics, including strengths and weaknesses, that could match many clients’ needs as well or better than the existing alternatives.

ACKNOWLEDGMENTS

We acknowledge the In it for Life (Vancouver Coastal Health) for their financial support, G.F. Strong for the trial space, study participants, and Dr. Bill Miller and Ms. Myra Butler for assistance with manuscript preparation.

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