Objective. The purpose of this study was to evaluate the ability of a basic driving simulator program to evaluate and train children with disabilities in their ability to operate a powered wheelchair.

Method. With a rating scale of skills considered essential for safe and efficient wheelchair operation, 22 children 7 to 22 years of age with either progressive muscular dystrophy or cerebral palsy were evaluated in their ability to drive a powered wheelchair through a driving course. They were divided into two groups: one without prior experience driving a powered wheelchair and the other with experience. After the driving assessment with an actual powered wheelchair, the inexperienced drivers were trained on a joystick-controlled computer game in which they navigated through labyrinths similar in layout to their own school environment. A test maze was administered before and after this training. Both groups were then evaluated on their ability to drive a powered wheelchair through the driving course.

Results. The inexperienced drivers significantly increased their simulator scores over the training period. Their wheelchair driving performance was significantly better after the simulator training, although their performance remained poorer than that of the experienced drivers.

Conclusion. A simulator program can assist in the development and evaluation of the skills required to operate a powered wheelchair.

Children who have motor impairments may have limited opportunities to experience normal interactions between their behavior and environmental consequences such that they fail to learn that they can control their surroundings (Brinker & Lewis, 1982; Swinth 1996; Swinth, Anson, & Deitz, 1993). This can lead to a lack of interest and a sense of helplessness with possible long-term repercussions, including the delayed learning of important skills such as cause and effect, choice making, and ways to exert control over the environment (Lahm, 1989; Swinth et al., 1993; Thelen, 1995). Furthermore, children whose mobility is restricted during early childhood may lack curiosity and initiation (Butler, 1986, 1988), traits that are believed to have a critical influence on intellectual performance and social interaction (Wright-Ott & Egelson, 1995). Therefore, mobility aids are recommended at as early an age as possible (i.e., by 24 months of age or sooner) (Bleck, 1977; Butler, 1988, 1991; Butler, Okamoroo, & McKay, 1984). At any age, a device that enhances independent mobility can improve the quality of life for persons with disabili-
ties as well as affect the person's confidence and self-esteem (Breed & Tbler, 1986).

An electric wheelchair is often a necessity for persons with physical disabilities who cannot propel a standard wheelchair or for whom doing so would require excessive energy. Powered wheelchairs are typically maneuvered with a joystick positioned near one of the arm rests or in the center of the chair. The driver grasps or pushes the joystick in the direction he or she wishes the chair to move. The speed can be proportional to the pressure applied to the joystick (force-control mode) or to the changes in joint position (position-control mode). Where the driver has difficulty controlling a joystick, an array of switches can be used (Bourhis & Pino, 1996; Kangas, 1997; Warren, 1990; Wright-Ott & Egilson, 1995).

Because of the high cost of purchasing a powered wheelchair, financial assistance is usually sought from government and public service agencies on the basis of recommendations from health care providers. Typically, an evaluation is carried out to determine the child's functional ability to perform the varied skills required to maneuver a powered chair. The evaluation focuses on physical abilities (e.g., proximal stability to enable distal control of whichever body part is manipulating the wheelchair, adequate muscle strength and endurance) and cognitive-perceptual abilities (e.g., visual perception, attention, memory, problem solving, planning, sequencing, eye-hand coordination) (Butler, Okamoto, & McKay, 1983, 1984).

Typically, initial driving performance is very poor because of a variety of factors, including a lack of optimal positioning and access adaptations and trepidation on the part of the child and parent, and some training is required to enable a fair evaluation of potential. This training can be costly as well as unsafe. Special “training chairs” are not always available (Thiers, 1994), particularly in school settings. As a result, applications for procurement of a powered wheelchair may be unfairly delayed.

Although there is no substitute for actual experience in driving a powered wheelchair (Kangas, 1997), we believe that some of these limitations could be overcome through the use of a computer program that simulates the operation of an electric wheelchair. Computers are already widely available in educational settings and are recognized as a useful tool in stimulating a child's motivation (Brant, Hooper, & Sugrue, 1991; Greenfield, 1984; McClurg & Chaille, 1987). Computerized games have been found to enhance spatial perception, eye-hand coordination, and problem-solving skills (McClurg & Chaille, 1987) and have been recommended as reliable, inexpensive substitutes for conventional psychomotor tests (Bliss, Kennedy, Turnage, & Dunlap, 1991; Jones, Kennedy, & Bittner, 1980). Furthermore, computerized simulators are assumed to be an efficient way to transfer learned skills to daily life (Horn, Jones, & Hamlett, 1991; Thompson & Chenn, 1988; Watson, Lange, & Brinkley, 1992; Yoder, 1993), although this is not always the case, and there is some debate as to the factors that determine when and whether transfer occurs (Gopher, Weil, & Barakett, 1994). Therefore, a driving simulation program would seem to be an inexpensive and safe way to train the skills involved in driving a powered chair as well as an effective way to determine when the required skills have been mastered.

The objective of this study was to explore whether a driving simulator would help a child master skills that are comparable to those required to drive a powered wheelchair. To this end, we developed an elementary computer game that required many of the skills necessary for controlling a powered chair. The game was operated by a position-controlled joystick typical of those used in electric wheelchairs and consisted of simple unidirectional tasks as well as navigation through mazes similar in layout to those in a school environment. Children with physical disabilities who had no prior experience at driving a powered chair were trained with the simulator program. Their performance on the simulator and their actual ability to drive a powered chair were tested before and after this training. Their performance on the computer and functional tests was compared with that of a group of children who were similarly disabled but who were already well experienced at driving a powered chair. It was expected that the inexperienced drivers' performance on the simulator would improve with training, which would lead to an improvement in their skill in operating an actual powered wheelchair, approaching the capability of the experienced drivers.

Method

Participants

Twenty-two participants were recruited from a school for children with disabilities in Israel. Participant characteristics are presented in Table 1. Their ages ranged from 7 to 22 years, with a mean age of 13.6 years. All had either progressive muscular dystrophy (PMD) or cerebral palsy of sufficient severity to preclude efficient use of a manually propelled wheelchair. Half of the participants (n = 11) had 1 to 5 years of previous experience using a powered wheelchair. The other half had no prior experience with a powered wheelchair but had been recommended to use one. The two groups were similar in age and level of cognitive ability as reported in their most recent psychological evaluations.

Instruments

Functional evaluation rating scale. In the absence of a standardized scale for evaluating driving ability, we devised a
functional evaluation rating scale. In accordance with guidelines recommended for instrument development (Benson & Clark, 1982), content validity of the scale was established on the basis of a questionnaire completed by 20 experts involved in prescribing powered chairs or in training persons with disabilities in their use. These experts included senior physical therapists and occupational therapists, teachers, and a rehabilitation engineer who all work with children with cerebral palsy and PMD. These professionals were considered to be experts because of their seniority (> 5 years experience prescribing and training this clinical population for powered wheelchair use), their ongoing participation in continuing education courses in this field, and their current or past receipt of supervision by more-senior therapists.

The questionnaire listed various skills involved in operating a powered wheelchair, including all the items considered by Butler et al. (1983, 1984) to be important for safe and efficient driving. The skills that were considered necessary by at least 70% of the 20 experts were incorporated into a rating scale for the functional evaluation.

The final scale consisted of the 12 criteria (see Appendix). Each criterion was assigned a rating from 1 to 4, which was defined operationally for the expert evaluators as follows: 1 = very good, indicating that the driver was able to carry out the task independently, correctly, and fluently; 2 = needs improvement, indicating that the driver could carry out the task but did so with moderate hesitation and with some verbal prompting; 3 = tries to perform, indicating that the driver hesitated and could not carry out the task; and 4 = is not able to perform, indicating that the driver was unable to initiate the task. For example, for criterion number 5, “passing through doorways without hitting walls,” a rating of 1 would be given to the driver who moved the wheelchair straight through the doorway and did not noticeably slow down or maneuver excessively in order to avoid hitting the doorjambs. A 2 would be given to the driver who was able to move through the doorway but did so excessively slowly, started and stopped the chair repeatedly while approaching the doorway, hit the doorjambs, or needed some verbal prompting. A 3 would be given to the driver who had difficulties similar to the driver rated with a 2 and, despite verbal prompting, was unable to move the chair through the doorway. A 4 would be given to the driver who was unable to initiate the task.

The participant’s score is the sum of the ratings for each item. Thus, the score can range from 12 to 48, with a lower score indicating better performance.

Simulation program. The simulation program was written in Turbo Pascal for use on a standard personal computer with a joystick. The program presented mazes of varying complexity on the computer screen. The goal was to use the joystick to guide the cursor from its starting position to an indicated end position, without hitting walls or barriers. In simpler mazes, the starting and ending positions were in the same “room.” In more complex mazes, the displays corresponded to the layout of different areas of the participants’ school, with the starting and ending positions located in different rooms. The walls of the rooms were outlined in different colors for ease of viewing. Depending on the level of difficulty selected, barriers may also appear in the lanes. These barriers could be stationary and present throughout the trial, or they could appear at random as the maze was traversed. An auditory tone was sounded on each collision.

The program recorded the time taken to complete the maze and the number of collisions. The score was calculated by allocating 1,000 points and then subtracting 1 point per collision and 1 point per second passed. Four levels of mazes were used for training, with three different mazes at each level. There was also one test maze at the highest level of difficulty that depicted an unfamiliar setting.

Procedure

All participants were evaluated in their skill on both the simulator program and with an actual powered wheelchair (using the functional evaluation rating scale). The group that was not experienced at driving a powered chair was evaluated twice: before and after training on the simulator program. The experienced driver group was only evaluated once because they did not receive simulator training.

For the functional evaluation, a course was constructed within the school. It was designed to reflect a typical route that a child might traverse in a wheelchair, with assorted obstacles (e.g., chairs, other children). Participants were required to drive along the course, stopping, starting, and turning according to verbal instructions. The inexperienced drivers were first given instructions on how to operate the chair and then were given practice manipulating the joystick with the power turned off. All partici-

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**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Inexperienced Drivers (n = 11)</th>
<th>Experienced Drivers (n = 11)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerebral palsy</td>
<td>9</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Progressive muscular dystrophy</td>
<td>2</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Age</td>
<td>13 ± 3.8</td>
<td>14.1 ± 3.8</td>
<td>13.6 ± 3.9</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>2</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Intelligence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>4</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Borderline</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Low</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

---
pants were allowed two practice runs before the actual evaluation. Typically, the functional evaluation took about 5 min.

Each participant's performance was evaluated with the functional evaluation rating scale at the same time by three evaluators who worked at the school. These evaluators had different professional backgrounds (senior occupational therapist, physiotherapist, teacher), and each had 13 years' experience in her field. The evaluators' ratings were summed to yield a total functional score for each participant. Combining the ratings in this way reflects the importance of giving equal weight to very different professional perspectives. The inclusion of disparate viewpoints would, not surprisingly, somewhat reduce the interrater reliability, but one would expect that provision of an explicit operational definition of the scoring criteria (as provided in this study and as discussed previously) would encourage the reliable and consistent use of the scale by different raters. Furthermore, although it was not possible to blind the evaluators as to whether participants were novice or experienced drivers, the evaluators were not aware of the purpose, format, or design of the study. The evaluators were also asked to provide an overall subjective evaluation of each participant's driving ability.

Simulator training involved exposure to the program for 30 min to 45 min twice a week for up to 12 weeks. Every participant in the inexperienced group started at the simplest level and continued until reaching the highest level. They received help in the form of verbal instructions and feedback. Three consecutive training sessions were devoted to each maze. Skill in using the simulator program was evaluated on two consecutive trials with the test maze. Only the scores for the second trial were used in the analyses.

Participants continued with their regular educational and therapy. These regimens had no particular impact on their ability to drive a powered wheelchair.

Results

Given the small sample size, nonparametric statistics were used throughout. The performance of the two groups on the functional tests is shown in Table 2. Spearman rank order correlations for the three evaluators, despite their different professional perspectives, revealed good interrater reliability. The correlations in eight of the nine comparisons ranged from .62 to .96 and were significant. Only the correlation between the pretest ratings of Evaluator 1 and Evaluator 2 (for inexperienced drivers) was not significant, $r = .46, p > .05$.

Before training on the simulator program, the total scores of the inexperienced drivers ranged from 36 to 126 (see Table 2). This was significantly poorer than the scores of the experienced drivers, which ranged from 36 to 50 (see Table 2; Mann Whitney $U = 9.5, p < .001$). All the experienced drivers scored as well as or better than the inexperienced drivers. After training with the simulator, the inexperienced group showed a significant improvement in driving performance (Wilcoxon signed rank $Z = -2.80, p < .01$). According to the ratings of all three evaluators, all but one of the inexperienced drivers showed an improvement after training. The only one who did not show an improvement was already performing at the highest level, even before training. Despite their improvement, however, the driving performance of the inexperienced group did not reach that of the experienced group, whose scores were still significantly better, $U = 19.5, p < .01$.

The simulator scores of the two groups are shown in Table 3. The maze scores of the experienced drivers ranged from 917 to 990 out of a possible 1,000. Initially, the scores of the inexperienced group were significantly less than those of the experienced group, $U = 30.5, p < .05$, ranging from 762 to 985. After training with the simulator, the maze scores of the inexperienced group ranged from 907 to 989, a significant increase, $Z = -2.93, p < .005$. All the inexperienced drivers improved their performance such that the difference between the two groups disappeared, $U = 56.5, p = .797$.

Discussion

The current study was undertaken to evaluate the ability of a wheelchair joystick simulator program to augment and assess the skills required to operate a powered wheelchair. Children with cerebral palsy and PMD who had no prior operating experience showed a marked improvement in their driving performance after training with the simulator. This result points to a substantial benefit from using such a program to prepare children for powered mobility.

Nevertheless, the wheelchair driving performance of the inexperienced drivers still fell short of that of the experienced drivers, most of whom had perfect or near-perfect scores. This was not unexpected, and may be attributed to a number of factors. First, the inexperienced drivers were given relatively short training periods with the simulator (no more than 45 min twice per week); the gap between the functional abilities of the two groups might have been narrowed had the inexperienced group been exposed to the simulator more frequently, for longer periods, with more mazes. Second, the two-dimensional simulator program used in this study was relatively basic and unsophisticated. Recently, "joystick trainers" have been made available commercially, and one can expect that, in time, simulators that attempt to be more "true to life," with three-dimensional graphics and elaborate sound effects that are based on virtual reality techniques, will be marketed. It has yet to be determined whether such
Table 2
Functional Test Scores of Participant Groups

<table>
<thead>
<tr>
<th>Participant</th>
<th>Inexperienced Drivers</th>
<th>Experienced Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Post Pre Post Pre Post Pre Post Pre Post</td>
<td>Eval 1 Eval 2 Eval 3 Total</td>
</tr>
<tr>
<td>1</td>
<td>28 17 25 14 20 15 73 46</td>
<td>1 12 12 12 12 12 36</td>
</tr>
<tr>
<td>2</td>
<td>21 21 15 12 12 13 48 46</td>
<td>2 17 22 16 16 16 36</td>
</tr>
<tr>
<td>3</td>
<td>43 21 27 21 23 23 93 65</td>
<td>3 12 12 12 12 12 36</td>
</tr>
<tr>
<td>4</td>
<td>42 25 27 21 24 18 93 64</td>
<td>4 12 12 12 12 12 36</td>
</tr>
<tr>
<td>5</td>
<td>12 12 12 12 12 12 36 36</td>
<td>5 12 12 12 12 12 36</td>
</tr>
<tr>
<td>6</td>
<td>23 14 22 13 22 13 67 40</td>
<td>6 12 12 12 12 12 36</td>
</tr>
<tr>
<td>7</td>
<td>26 18 16 12 15 12 57 42</td>
<td>7 12 12 12 12 12 36</td>
</tr>
<tr>
<td>8</td>
<td>21 15 18 17 20 15 59 47</td>
<td>8 12 14 14 14 14 36</td>
</tr>
<tr>
<td>9</td>
<td>29 23 24 21 28 21 81 65</td>
<td>9 12 12 12 12 12 36</td>
</tr>
<tr>
<td>10</td>
<td>27 17 26 16 29 17 82 50</td>
<td>10 12 12 12 12 12 36</td>
</tr>
<tr>
<td>11</td>
<td>39 34 43 35 44 31 126 100</td>
<td>11 12 12 12 12 12 36</td>
</tr>
</tbody>
</table>

Note: The experienced drivers were tested once. The inexperienced drivers were tested before (pre) and after (post) simulator training. Scores can range from 12 to 48, with a lower score indicating better performance. Eval = evaluator.

Table 3
Computer Simulator Scores for Participant Groups

<table>
<thead>
<tr>
<th>Participant</th>
<th>Inexperienced Drivers</th>
<th>Experienced Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretraining Score Posttraining Score</td>
<td>Participant Score</td>
</tr>
<tr>
<td>1</td>
<td>954 962</td>
<td>1 962</td>
</tr>
<tr>
<td>2</td>
<td>872 952</td>
<td>2 963</td>
</tr>
<tr>
<td>3</td>
<td>793 954</td>
<td>3 996</td>
</tr>
<tr>
<td>4</td>
<td>965 969</td>
<td>4 961</td>
</tr>
<tr>
<td>5</td>
<td>985 989</td>
<td>5 981</td>
</tr>
<tr>
<td>6</td>
<td>952 967</td>
<td>6 917</td>
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<tr>
<td>7</td>
<td>939 968</td>
<td>7 927</td>
</tr>
<tr>
<td>8</td>
<td>962 963</td>
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<td>939 963</td>
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<tr>
<td>10</td>
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<td>10 978</td>
</tr>
<tr>
<td>11</td>
<td>762 907</td>
<td>11 970</td>
</tr>
</tbody>
</table>

M ± SD 916 ± 74.3 960 ± 20.9 M ± SD 960 ± 21.8

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Acknowledgments
We thank the staff and pupils of the On School for their participation in this study. We also thank the Ilan Association for Disabled

sophisticated simulators will be more effective or whether the increased perceptual demands might actually be a hindrance for some persons with perceptual impairments, such as those with cerebral palsy. The most likely explanation for the continuing gap is that children will only fully integrate the skill of wheelchair driving after they actually engage in the task (Brant et al., 1991; Kangas, 1997; Pronk et al., 1980).

Thus, the results of this study should not be taken to imply that simulator training alone could or should substitute for experience with an actual powered wheelchair. Maneuvering a wheelchair in a noncontrolled environment is a complex task, requiring the constant integration of sensory, motor, and cognitive-perceptual systems, and it is very difficult to predict or simulate all possible conditions and events. We advocate the use of the wheelchair driving simulator in the absence of an opportunity to engage in and as preparation for actual driving experience. Given current funding limitations and skepticism on the part of those responsible for funding powered chairs, it is often up to the therapist to demonstrate a child's ability to drive even before he or she has had an opportunity to do so. We propose the use of the driving simulator to help the child get a powered chair so that he or she can then perform in a natural environment.

Our results demonstrate that training with a basic simulator program can lead to an appreciable improvement in functional performance on an actual powered wheelchair. Thus, if an evaluation of driving skill were conducted after simulator training, the client's performance will be enhanced, and a more reliable determination could be made of the client's abilities and potential. If the simulator training were preceded as well as followed by a functional evaluation, as was done in this study, then it would make for an even more reliable recommendation because the evaluator would also have an indication of the client's potential for improvement over time.

The encouraging results of this initial study, obtained with such a basic simulator program, present a strong argument for further research. According to a critical review of flight simulation research conducted by Hays, Jacobs, Prince, and Salas (1992), the effectiveness of simulator training is influenced considerably by the type of task and the amount and type of training given. Therefore, future research should be directed toward determining the optimal training schedule and the most appropriate task for different types of disabilities. A more extensive study might also use larger samples, including a sample of inexperienced drivers who would not undergo simulator training.

Simulator training is an inexpensive and safe first step in developing and assessing the skills necessary for operating a powered wheelchair. The results of a simulator evaluation can contribute toward recommendations to health insurance providers and government sources in conjunction with evaluation on a chair where feasible.
Children for financial support and Alon Parag for programming the wheelchair simulator program. The first author carried out this study while a student in the master’s of science degree program in Medical Sciences, Faculty of Medicine, Hadassah-Hebrew University.

Appendix
Rating Scale Used for the Functional Evaluation

Values for the following scale items were 1 = very good; 2 = needs improvement; 3 = tries to perform; and 4 = is not able to perform:

1. Starting and stopping wheelchair at will
2. Starting and stopping upon request
3. Driving straight (for 3.5 m) in an open area
4. Driving straight (for 3.5 m) in an narrow corridor without hitting walls
5. Passing through doorways without hitting walls
6. Turning 360°
7. Turning around a 90° corner
8. Driving backward (.5 m) in a straight line
9. Approaching people or furniture without bumping into them
10. Driving to a specific location decided on in advance
11. Turning right and left at will and upon command
12. Planning a trip from one location to another in an efficient manner

References


