Wheelchair Curb Climbing: Randomized Controlled Comparison of Highly Structured and Conventional Training Methods

R. Lee Kirby, MD, FRCP, Sean Bennett, BSc, Cher Smith, BSc, Kim Parker, MSc, Kara Thompson, MSc


Objectives: Our primary objective was to test the hypothesis that a highly structured training method for wheelchair curb-climbing requires less training time than conventional training. Our secondary objectives were to test the hypotheses that this training method increases success rate, reduces the need for spotter interventions, and reduces the participants’ perceptions of difficulty.

Design: Randomized controlled trial.

Setting: Rehabilitation center.

Participants: Able-bodied participants (N=16), randomly allocated to intervention (n=7) and control (n=9) groups.

Interventions: Both groups received up to 5 training sessions. Each session included instruction, practice, and feedback. The participants in the intervention and control groups used 18- and 9-step approaches, respectively. Training in the intervention group also included video demonstration, trainer demonstrations, mirror feedback, and standardized feedback phrases.

Main Outcome Measures: Total training time, success rate at climbing a 15cm-high curb, the number of spotter interventions during training, and a questionnaire.

Results: The mean ± SD training times for the successful participants in the intervention and control groups were 42.5±24.4 minutes and 87.4±45.3 minutes (P=0.084). The curb-climbing success rates of the intervention and control groups were 86% and 89% (P=1.000). There were no significant differences between the groups regarding the number of spotter interventions (P=0.203) or for participants’ perceptions of difficulty (P=0.050).

Conclusions: In comparison with a conventional method for curb-climbing, a highly structured method seems to require less than 50% of the training time for able-bodied participants, although this finding is only a trend statistically. This has implications for clinical training.

Key Words: Accessibility; Architectural; Motor skills; Rehabilitation; Wheelchair.

THERE IS GROWING EVIDENCE that a more formal approach to wheelchair skills training is beneficial. The Wheelchair Skills Program for users of manual wheelchairs includes skills that span a broad range of difficulty levels. One important, but potentially dangerous, skill is the curb ascent. Although pedestrian ramps are common at street corners in North America, they are far from universal. Conventional curbs are 15cm high but level changes of smaller heights in indoor and outdoor settings are also common.

Ascent of a 15cm-high curb is a skill that only a small percentage (<1%) of wheelchair users can perform. Best et al showed that, with training of 20 community-dwelling wheelchair users (age range, 21–77y, half with musculoskeletal and half with neurologic disorders), this prevalence can rise to 20%. One possible reason why so few wheelchair users are capable of performing a curb climb is that the most appropriate method of teaching people to climb curbs is unknown.

For manual wheelchair users who have little leg function and use the 2-handed propulsion method, ascending a 15cm-high curb usually consists of 3 phases (table 1; fig 1). In the approach phase, the wheelchair user propels the wheelchair towards the curb with sufficient speed to provide the momentum to ascend the curb and with sufficient directional control to strike the curb squarely. In the caster-pop phase, the wheelchair user induces sufficient rear pitch of the wheelchair for the casters to slightly clear the curb. This is usually accomplished by applying forward forces to the hand rims of the rear wheels. In the rear-wheel-ascent phase, when the rear wheels strike the curb and the casters land on the upper level, the wheelchair user leans forward and may apply additional forward forces to the hand rims. For curbs or level changes of lesser height or when using less common techniques, a successful curb climb may be possible without the approach phase.

Evidence from the literature on motor skills learning suggests the importance of structuring the learning experience. Although MacPhee et al and Best have provided data on the success rates of training in which curb climbing was one of several skills trained, there are no published data regarding training time, the need for spotters, or participants’ perceptions specifically with respect to curb-climbing. What constitutes

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>BMI</td>
<td>body mass index</td>
</tr>
<tr>
<td>VAS</td>
<td>visual analog scale</td>
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</tbody>
</table>
Recruitment and Screening

Participants provided informed consent. Ethics Board of the Capital District Health Authority. All Ethical Considerations were screened for inclusion and exclusion criteria (below) by self-report and by their performances in the warm-up phase of training session 1.

### Inclusion and Exclusion Criteria

Participants were at least 17 years old, had body sizes that fit the wheelchair used, and were able to follow instructions. To ensure that the participants possessed at least a moderate degree of skill, coordination, and strength, we required them to be able to perform basic wheelchair skills. These were brake handling, rolling forward and backward, moving turns forward and backward, and handling a 5° incline (ascent and descent). Potential participants were excluded if they could already perform a 15cm curb climb or if they had any unstable medical conditions by self-report. None of the participants could perform advanced wheelie-based skills.

### Group Allocation

Participants were assigned to the intervention or control groups in a random block fashion, using a random number generator, stratifying for sex (which is known to affect wheelchair skills performance). 11

### Wheelchair

A single rear-wheel-drive rigid-frame manual wheelchair was used by all participants for training and testing. The sling seat was 46cm high, 41cm wide, and 46cm deep, covered with a contoured polyurethane cushion. The rear wheels were 61cm in diameter and were set in 3° of camber. They had pneumatic tires, wire spokes, and metal push rims. The centers of the axles were set 12cm below the seat rails and 3.5cm in front of the back post. The solid casters were 13cm in diameter. The hanger angle of the fixed footrests was 80°. Rear anti-tip devices were removed. The chair had no armrests and the footrest was nonadjustable. The chair (including cushion) weighed 12.4kg.

### Safety

The trainer and tester served as spotters. A spotter strap was attached to the lower rear frame of the wheelchair and it was held by the spotter to prevent accidental rear tipping. The spotter was also alert to other dangers, such as the participant falling forward from the wheelchair when the wheelchair struck the curb or the wheelchair tipping to the side if 1 rear wheel ascended the curb before the other.

### Training Procedures

Each training session lasted 37 minutes or less, at a target frequency of 1 to 3 sessions a week. Successful participants continued in training until curb-climbing competence was achieved and confirmed by a retention test. If competence was not achieved before the maximum allowable 5 training sessions, the participant was considered to have been unsuccessful and his/her involvement in the study was over.

There was a single trainer for both groups. Except as noted below and summarized in table 2, both groups followed the same training procedures. The general format for a training session was as follows. Each training session began and ended with warm-up and cool-down periods of 2.5 minutes each. These consisted of performing the skills described above in the inclusion criteria, but did not include any attempts at curb-climbing. The warm-up was followed by training in curb-climbing. If the participant achieved competence, or if the participant wished to stop the session early (eg, due to fatigue), the session was terminated and the reason noted. We based progression from 1 step to the next on successfully and safely

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### Table 1: Phases and Events of the Wheelchair Curb-Climbing Skill

<table>
<thead>
<tr>
<th>Event No.</th>
<th>Event Name</th>
<th>Defining Events</th>
<th>Start No.</th>
<th>End No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Onset of final push</td>
<td>Onset of final forward application of force to hand rims, excluding any pop-related hand rim forces.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Onset of pop</td>
<td>Onset of action (eg, application of forces to hand rims, body movement) intended to pop the casters from the lower surface.</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Caster lift-off</td>
<td>The instant that the casters lift from the lower surface.</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Rear-wheel contact</td>
<td>The instant that the rear wheels make contact with the curb.</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Rear-wheel landing</td>
<td>The instant that the rear wheels are fully on the upper surface.</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>User upright</td>
<td>The instant that the wheelchair user is sitting upright and prepared for further action.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
performing the previous level twice consecutively. When the
15cm curb climb could be successfully and safely performed,
training ceased and a retention test was scheduled. Both groups
received instruction, practice, and feedback, consistent with the
principles of the Wheelchair Skills Program. Feedback was in
the form of prescriptive knowledge-of-performance statements
(identifying the single suggestion that the trainer believed
would be most helpful at that stage of training). Feedback
began on a 50% feedback schedule (ie, only after every second
attempt) and the frequency decreased over time.

Control group. The conventional training method included
9 steps (see table 2). The learner first attempted a 5cm curb
climb, followed, when successful, by a 10cm and a 15cm
climb. At each level, the learner began with a stationary
method (phases 2 and 3 from table 1), followed by the moving
method (all 3 phases from table 1) if he/she was able to get the
casters up on the upper level but was unable to get the rear
wheels up.

Intervention group. This group underwent an 18-step pro-
cess (see table 2), beginning with an earlier series of skills to

Fig 1. In the approach phase (A), the wheelchair user approached the 15cm-high curb squarely, rapidly, and with the hands ready to apply
forward forces on the hand rims at the appropriate moment. In the caster-pop phase (B), the wheelchair user accelerated the rear wheels,
causing the casters to lift from the surface. In the rear-wheel-ascent phase (C), the wheelchair user leaned forward and applied another push
to the hand-rims. Once on the curb (D), the wheelchair user sat upright. Throughout the skill, the single spotter held a spotter strap loosely
in the right hand and held the left hand near the wheelchair user’s shoulder.
progress through before beginning the curb heights. The intervention group started each skill level with popping the casters over progressively more difficult obstacles while stationary, and then leaning forward to help bring the rear wheels over the obstacle. The moving approach was then added, and the participants practiced performing all 3 components of the skills (ie, approach, caster pop, and rear-wheel ascent) on the same series of obstacles.

In addition to the more finely grained progression of difficulty for the intervention group, we took care to incorporate some additional principles of motor skill learning. Participants viewed a short videotaped demonstration of a skilled person performing the skills during training session 1. The trainer also demonstrated skills as a means of providing instruction as needed during the training sessions. A full length mirror, angled 45° to the obstacle edge, was used as necessary, to provide the participants with visual feedback. The trainer gave prescriptive knowledge of performance feedback from a list of standard phrases (eg, as you approach the curb, place your hands further back on the hand rims, at about 11 o’clock).

### Retention Test

The retention test was administered a minimum of 3 days after the final training session. The retention tester was blind as to group allocation. Participants began with a general warm-up for 2.5 minutes (as for training sessions), followed by practice of curb-climbing (without feedback), for up to 2 minutes. The tester then administered the Curb Climbing Competence Test. Success consisted of the participant climbing the 15cm curb successfully and safely twice consecutively. Following this, participants cooled down for up to 2.5 minutes (as for training sessions).

### Outcome Measures

The primary outcome measure was the total training time (including the duration of the first retention test if the participant failed and resumed training). Training time was measured to the nearest minute, using a stopwatch started and stopped at the beginning and end of each session. Secondary outcome measures were eventual success or failure on the Curb Climbing Competence Test, the total number of spotter interventions (using a counter) and the participants’ perceptions about the training (using a questionnaire). The questionnaire included questions for which VASs were used to quantify the answers, as well as open-ended questions.

### Procedure

After enrollment, the collection of demographic data and informed consent, we allocated the participants to a group and training began. When the curb-climbing skill was apparently mastered during a training session, training stopped and a retention test was scheduled. If the participant passed the Curb Climbing Competence Test at the first retention test, the questionnaire was administered and the participant’s involvement was complete. If the participant failed the Curb Climbing Competence Test at the first retention test and had not already had a total of 5 training sessions, additional training was scheduled. If successful during this subsequent training, a second and final retention test was scheduled. Regardless of the result of the second retention test, the questionnaire was administered and the participant’s involvement was complete. If a participant completed all 5 training sessions without achieving curb-climbing competence, the questionnaire was administered and the participant’s involvement was complete.

### Statistical Analysis

We used SAS (version 9.1) statistical software. Descriptive statistics were calculated. Where appropriate, the normality of the data was assessed to guide the choice of parametric versus nonparametric statistics. For the main outcome measure (training time) only, we compared training time just for the successful participants and we used Wilcoxon 2-sample rank-sum tests. All tests were 2-sided. To assess group comparability, we compared sex (Fisher exact test), age (2-sample t test), height (2-sample t test), weight (2-sample t test), BMI (2-sample t test), and a process measure (number of days between training sessions 1 and 2). For success rate, we used Fisher exact test. Wilcoxon 2-sample t tests were used to analyze the spotter interventions and the VASs. The α level for the primary outcome measure (training time) was 0.05. For the secondary measures (success rate, spotter interventions, and perceived difficulty), the α level was Bonferroni-adjusted to 0.0125 (0.05/4) to avoid the problem of multiple comparisons. The comments from the questionnaires were reported descriptively.

### RESULTS

#### Participants

Of the 16 participants, 7 were allocated to the intervention group and 9 to the control group. Their characteristics are shown in table 3. Two other participants dropped out due to scheduling conflicts; they were both in the intervention group.

#### Group Comparability

There were no significant differences between the groups for sex (Fisher exact test), age, height, weight, BMI, or the number of days between training sessions 1 and 2. 

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**Table 2: Intervention Versus Control Group Training Protocols**

<table>
<thead>
<tr>
<th>Step No.</th>
<th>Obstacle</th>
<th>Phases Practiced</th>
<th>Intervention Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taped line on floor</td>
<td>2, 3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Pothole (15cm across)</td>
<td>2, 3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Threshold (2cm high)</td>
<td>2, 3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Curb (5cm high)</td>
<td>2, 3</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Curb (10cm high)</td>
<td>2, 3</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>Curb (15cm high)</td>
<td>2, 3</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Taped line on floor</td>
<td>1, 2, 3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>Pothole (15cm across)</td>
<td>1, 2, 3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Threshold (2cm high)</td>
<td>1, 2, 3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>Curb (5cm high)</td>
<td>1, 2, 3</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>11</td>
<td>Curb (10cm high)</td>
<td>1, 2, 3</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>12</td>
<td>Curb (15cm high)</td>
<td>1, 2, 3</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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*From Wheelchair Skills Program.*

†The 3 phases of the curb-climbing skill are (1) approach, (2) caster pop, and (3) rear-wheel ascent, as defined in table 1.

§If unsuccessful, the participant proceeded to step no. 13 (intervention group).

‖If unsuccessful, the participant proceeded to step no. 16 (control group).

§If successful, training ended for either group.
Training Time

The mean ± SD training times for successful participants in the intervention and control groups were 42.5±24.4 minutes (median, 34.0; range, 25–91) and 87.4±45.3 minutes (median, 74.5; range, 27–147) (fig 2). The SD of the difference was ±38.0 minutes. The 2-sided P value from the Wilcoxon rank-sum test was .084. Each group had 1 participant who did not successfully complete training; their training times were 69 and 152 minutes for the participants in the intervention and control groups, respectively. Four participants (3 in the intervention group and 1 in the control group) required only a single training session. The mean ± SD number of training sessions for the intervention and control groups were 2.3±1.6 and 3.0±1.4 (P=.294).

Success Rate

The curb-climbing success rates for the intervention and control groups were 86% and 89% (P=1.000) (see fig 2).

Spotter Interventions

The mean ± SD total number of spotter interventions during training was 5.3±4.9 for the intervention group and 8.8±4.9 for the control group (P=.203) (see fig 2). No participants in this study experienced dangerous tips, because the spotter was able to stop or slow the falls. The most difficult problems to spot were forward tips and falls if the casters struck the curb and sideways tips when the rear wheel on 1 side of the wheelchair ascended the curb before the other. What made the sideways tips particularly difficult to spot was that it was not possible to predict in advance which rear wheel would ascend first.

Participants’ Perceptions

The results from the questions using VASs to quantify the answers are shown in table 4. There was no significant difference between the groups regarding the participants’ perceptions of difficulty (P=.05), although a trend was identified in favor of less difficulty for the intervention group (see fig 2). The levels of satisfaction were high (means of 76%–96%) for training time, feedback provided, trainer effectiveness and effectiveness of the training method; but there were no statistically significant differences between the groups for these parameters.

The qualitative comments from participants in the 2 groups were similar in some instances and varied in others. In answer to the question, If you could change anything about your training, what would it be?, the control group answers included 3 requests for demonstrations of the skill. In answer to the question, How was the trainer effective in helping you learn?, participants in both groups commented on the trainer’s feedback (7), friendliness (7), and patience (4). In answer to the question, How do you think the training method was effective in helping you learn the skill?, there were 2 answers about the progression of steps. The control group answers included, Learning by doing was extremely effective . . . and, Made me attempt to solve my own problems. The intervention group answers included 3 positive comments about the demonstrations. In answer to the question, Do you have any suggestions to improve this training for actual wheelchair users?, the control group answers included 3 suggestions that demonstrations should be used. In answer to the question, What was the most difficult part of your training?, there were 8 answers that indicated the difficulty of the rear-wheel-ascent phase and 3 about the difficulty of the approach phase.

DISCUSSION

This study partially corroborated the hypothesis that a highly structured training method for wheelchair curb-climbing requires less training time than a traditional method of training requires. The magnitude of the reduction in training time was considerable (less than half), but the difference was not statistically significant (P=.08 for the 2-sided test). As a post hoc measure, because we had a clear preconceived expectation about the direction of the difference between the groups (ie, that the intervention would reduce the training time), we also performed a 1-sided Wilcoxon 2-sample rank-sum test on the training time data. The 1-sided P value was .042. From the
perspective of statistical significance, we conclude that the difference between the groups was, at best, barely significant ($P = 0.042$) and, at worst, a trend ($P = 0.084$). From the perspective of clinical significance, if the reduction in training time was real, this would have potential benefits for wheelchair users because the period of initial rehabilitation is a busy one. It would also have benefits for the therapist doing the training, allowing him/her to use the saved time to address other issues or other patients.

The success rates for the 2 groups did not differ significantly. Given that both groups had success rates of 86% or more, a ceiling effect may have affected our ability to detect a difference. It seems that 5 training sessions is adequate time for most young able-bodied people to learn the wheelchair curb-climbing skill. If the maximum number of training sessions had been set at 3, there would have been a 57% success rate in the intervention group and a 55% success rate in the control group. When this study is replicated with actual wheelchair users, a difference in success rate may be seen.

The mean number of spotter interventions was lower in the intervention group, but not to a statistically significant extent ($P = 0.088$). The small effect size and the high variability in these data suggest that a larger sample size would be needed to determine if a real difference exists. This study provided new insights about spotting technique, in particular the difficulty for a single spotter to provide protection against multiple risks (i.e., rear tips, forward falls from the wheelchair, and lateral tips if 1 rear wheel ascends before the other). The spotter strap functioned well in dealing with rear tips. A seat belt or a second spotter (fig 3) would provide better protection against forward falls. To prevent lateral tips (fig 4), we recommend additional spotters, if available.

The posttraining questionnaire provided numeric and qualitative data about the participants’ perceptions on training methods and what could be done to improve them. The mean perceived difficulty of the curb-climbing skill, as determined by the VAS scale was only mild to moderate (means of 28% and 53%) for the intervention and control groups, respectively. The difference was not statistically significant ($P = 0.05$). Based on the other VAS scales (see table 4), participants in both groups were very positive about their training experiences. The qualitative comments revealed the participants’ perceptions about the importance of demonstration, feedback, the trainer’s manner, and which phase of the skill was most difficult (rear-wheel ascent).

**Study Limitations**

One limitation of this study was the small sample size. Although marginally adequate to assess the primary hypothesis on training time, given that the variances of the data were larger than expected, a larger sample size would have allowed us to more convincingly answer the question about whether the difference was statistically significant. There was also insufficient power to adequately assess some of the secondary objectives. Another important limitation of this study was the use of young able-bodied participants. Although the principles of motor learning apply to both wheelchair users and non-wheelchair users, it is known that personal characteristics (e.g., age, sex, and diagnosis) affect wheelchair skill performance. We used only a single wheelchair for this training. Although this reduced 1 source of variability, wheelchairs with different characteristics would likely affect the results. Another limitation was the single-blinded nature of the study.

Another limitation was that some of the teaching aids (e.g., full-length mirror, training video) would not be readily available in all training settings. Also, to provide the trainee with live demonstrations, the trainer must be able to perform the skill him/herself or have someone (e.g., a peer trainer) available who can. Because of the large number of failures on the first retention test, we now recognize that we should not have stopped training immediately after a participant showed curb-
climbing success. We should have permitted a further period of training (the overlearning principle)\textsuperscript{15} to ensure that the skill had been retained. Future study is required to address these limitations.

Despite the study limitations and the need for further study, this study was the first to assess the training time required for wheelchair curb-climbing. The data on success rates, spotter interventions, and participants’ perceptions will inform future work.

**CONCLUSIONS**

In comparison with a conventional method for curb-climbing, a highly structured method seems to require less than 50\% of the training time for able-bodied participants, although this finding is only a trend statistically. This has implications for clinical training.

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**References**


**Suppliers**

a. Competitor model; Everest & Jennings, GF Health Products, Inc, 2935 Northeast Parkway, Atlanta, GA 30360-2808.
b. Jay combi model; Sunrise Medical Canada, 237 Romina Dr, Unit 3, Concord, ON, L4K 4V3.
c. ABS Tally Counter; Tally Counter Store, 8962 Leavenworth Rd, Leavenworth, WA 98826.