Proactive Balance Strategy While Maintaining a Stationary Wheelie

James P. Bonaparte, BSc, R. Lee Kirby, MD, Donald A. MacLeod, MSc


Objective: To test the hypothesis that a reactive balance strategy is used while maintaining a stationary wheelie, specifically that a forward pitch from the wheelie equilibrium position is associated with a forward displacement of the wheelchair and a rear pitch with rear displacement, with the displacement slightly after the change in pitch.

Design: Descriptive and quantitative kinematic analysis.

Setting: Kinesiologic laboratory.

Participants: A convenience sample of 10 able-bodied adults.

Intervention: Subjects taught to pop and maintain a stationary wheelie for 15 seconds while remaining within a .75 × .75 m². Three trials of 5 seconds; digitized targets videotaped for analysis.

Main Outcome Measures: Pitch angle and rear-wheel position of the wheelchair, derived from digitized videotape and time-series analysis of phase lag.

Results: There was an inverse relationship between the direction of pitch and linear displacement—rear pitch was associated with forward wheel displacement and forward pitch was associated with rearward wheel displacement. The mean pitch angle ± standard deviation was 13.6° ± 2.3° and the mean horizontal position of the wheelchair was 0.0 ± 4.9cm. There was little or no phase lag between pitch and displacement.

Conclusions: Wheelie performers maintaining a stationary wheelie appeared to use a proactive balance strategy, in which they used a functional base of support that was larger than the geometric one. These findings may have significance for those who are learning and teaching wheelies and provide broader insights into the nature of dynamic balance.

Key Words: Balance; Biomechanics; Rehabilitation; Wheelchairs.

© 2001 by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation

Although much research has been conducted on wheelchair propulsion, the literature contains little about the wheelchair wheelie.1-5 A wheelie is executed when the user pops the front casters off the ground and balances on the rear wheels. A wheelie is useful in various situations, for instance, when an individual must climb a curb, turn in confined spaces, or negotiate uneven terrains.1-2 However, most wheelchair users never master this skill, in part because wheelies are potentially dangerous to practice if unsupervised.1,2

Wheelchair-related injuries caused by tips and falls are common and often serious.6-8 If an individual tips the wheelchair too far backward and strikes his/her head on the floor, the impact would be more than sufficient to fracture the skull or to drive a pin from a halo into the skull.9 The wheelchair user’s fear of tipping over backward is among the most difficult obstacles to overcome when teaching a wheelie.2 In addition to safety concerns, many therapists cannot perform the skill themselves and may, therefore, lack the confidence to teach it. Also, efforts to contain the costs of rehabilitation can result in insufficient time and human resources available to teach more than basic wheelchair skills.

To understand wheelie balance, it helps to consider the analogy of standing balance. Postural stability, during quiet standing, is the ability to control the position of the center of mass (COM) with respect to the base of support (BOS). If an unexpected perturbation occurs that displaces the COM toward the boundaries of the BOS, corrections will be made to this system, displacing the COM in the opposite direction. For standing balance, the ankle strategy (using ankle muscles to alter the COM position over the stationary feet) and the hip strategy (using hip and upper body movements) are types of synergies people use to respond to postural perturbations.10,11 If balance cannot be accurately corrected by moving the COM in these ways, then the person will respond by taking a step in the direction that the COM was displaced (the step strategy), thereby moving the BOS under the COM rather than the converse.10

In the case of the stationary wheelie, static balance is almost impossible because of the small BOS. Perturbations would appear to require the wheelchair user to react by exerting forces on the handrim to rotate the rear wheels, thus translating the BOS under the COM, most analogous to the step strategy. This reactive balance theory, though it makes teleologic sense and is assumed to be the case by a number of investigators,1-5 has not been validated or quantified.

The primary purpose of this study was to evaluate whether a reactive balance strategy is used to maintain a stationary wheelchair wheelie. Specifically, we hypothesized that a forward pitch from the wheelie equilibrium position would be associated with a forward displacement of the wheelchair and a rear pitch would be associated with a rear displacement of the wheelchair, with the displacement slightly after the change in pitch. Secondary purposes were to quantify the pitch changes and linear displacements of the wheelchair during these activities and to describe strategies used in popping and maintaining wheelies.
METHODS

Subjects
We studied 10 able-bodied subjects, a convenience sample, after obtaining informed consent. The study was approved by the Research Ethics Committee of the Queen Elizabeth II Health Sciences Centre, Halifax, Canada. We considered the sample size to be adequate for a preliminary descriptive study such as this. Subjects met a number of inclusion criteria: they were between 18 and 40 years of age, had a body size that fit the single wheelchair used, did not ordinarily use a wheelchair for mobility (to avoid confounding variables related to the reasons for wheelchair use), did not have a medical condition that affected the range of motion or strength of the upper limbs, did not have a medical condition that affected balance, and were able to learn to perform a wheelie. The subjects’ mean ± standard deviation (SD) age, height, and weight were 20.9 ± 1 years, 1.70 ± .06 meters, and 66.2 ± 8.6kg, respectively.

Wheelchair
To control for variability among wheelchairs, we used a single lightweight, rear-wheel-drive manual wheelchair for all training and testing. The wheelchair was equipped with 61-cm diameter rear wheels, 12-cm diameter casters, and solid foot rests. The seat was 48cm high, 43cm wide, and 43cm deep with a 3-cm seat cushion. The axle was positioned in the most posterior setting, and the axle height was set at the second position from the bottom, creating a seat angle of 6.5°. These wheelchair settings remained constant for all subjects.

Training
Subjects attended a maximum of 3 30-minute training sessions, all within 1 week. During the initial training session, the trainer showed the skills and instructed the subject how to perform a stationary wheelie. The trainer also gave subjects information on the usefulness of wheelies and the associated potential dangers. The trainer used a spotter strap, attached to a rigid portion of the wheelchair frame, to prevent the subject from tipping too far backward. When possible, subjects were given the opportunity to test the spotter strap by allowing them to experience what it was like to catch the trainer during a deliberate rear-tip.

The trainer gave little information to the subjects regarding the performance of a wheelie, except for the following information that had been derived from the literature. The trainer advised each subject to keep the trunk flat against the backrest, primarily relying on handrim forces to control the wheelchair. Subjects were informed that a loss of balance would require a movement of the wheelchair in the same direction to regain balance. The trainer encouraged subjects to relax and provided feedback on performance.

Subjects learned to perform 3 wheelie skills: (1) popping and maintaining a stationary wheelie for 15 seconds while remaining in an area 7.5 × 7.5m², (2) rolling forward 1 meter while in a wheelie position, and (3) rolling backward 1 meter while in a wheelie position. Success at learning these skills was an inclusion criteria. Although we only studied the first of these skills (maintaining a wheelie), we taught the other 2 because we wanted subjects to have more than a minimal skill level. Kauzlarich and Collins defined the skill level of individuals by the amount of time that they could maintain balance over the rear wheels. They defined less than 10 seconds as poor, 10 to 60 seconds as intermediate, and greater than 60 seconds as highly skilled performance.

Video Recording
Testing was conducted in a kinesiologic laboratory. We used a videocamera, set at a shutter speed of 250 Hz, to record the performance of the subject at 30 frames per second from the right lateral perspective, having positioned the center of the camera lens 0.7 meters from the floor and 7.3 meters from the right side of the wheel chair. The camera recorded for 5 minutes before testing, to warm up.

Testing Protocol
All testing was conducted within 2 to 7 days after the subject learned the 3 skills. We placed digitizing targets on the center of the rear axle and on the anterior chair frame above the footrests. Subjects were given a 5-minute warm-up to practice the stationary wheelie. Subjects then placed the wheelchair in the designated position relative to the videocamera. We instructed subjects to perform a stationary wheelie for 15 seconds, trying to maintain balance while remaining in a 0.75 × 0.75 meter box.

Once a subject popped the front casters off the ground, we began the timing. At 5 seconds, we triggered a flash to indicate this point on the videotape. For the 15-second trial, we did not digitize the initial and final 5 seconds because of the possible initial effects of popping the wheelie and the late effects of returning to the ground. We considered the middle 5 seconds to be the time when the subject was maintaining a stationary wheelie. Each subject performed 3 trials. The first trial was considered to be practice in front of the camera and, thus, was not digitized. If a subject was unable to maintain the wheelie for 15 seconds, it was considered a mistrial and was repeated.

Data Analysis
We recorded general descriptive data during the training sessions to gain insight into the learning process. Descriptive information was also recorded from the 45 seconds of videotape data (15s for each of the 3 trials), including the number and cause of discarded trials (when the subject did not achieve or maintain balance for 15s) and the popping strategy used.

During the middle 5 seconds of the 2 digitized trials, we digitized the coordinates of the digitizing targets and an origin at 60 Hz (30 frames/s = 60 fields/s) by using an analysis system. Data were filtered by using a fourth-order 0-lag Butterworth digital filter.

Linear movement of the rear wheels in the rear direction was defined as an increase in displacement (positive), whereas forward movement was defined as a decrease in displacement (negative) (fig 1). Pitch was defined as the difference between the angle of a line connecting the digitizing targets and the horizontal with the wheelchair at rest and the angle during the wheelie. A rear pitch was defined as an increase in wheelchair pitch angle (positive) and a forward pitch as a decrease (fig 1).

We calculated descriptive statistics (maximum, minimum, mean, SD) for the pitch angle and the linear displacement of the wheelchair and used a Pearson correlation coefficient and a matched pairs t test to evaluate within-subject reliability between trials. Statistical significance was defined as p < .05. We plotted the pitch angle and linear displacement of the wheelchair against time to allow a qualitative and descriptive analysis for each subject. We used time-series analysis and cross-correlation with each digitized trial (n = 20) to determine if phase lags were present between the pitch and displacement of the wheelchair. Correlations were calculated from k = −20 to k = 20, with each change in k corresponding to a shift of 1/60 second of the pitch data relative to the displacement data. The k value resulting in the maximum correlation indicated the extent of any time lag between the 2 data sets.
subjects had a relatively posterior hand position on the hand-extension and elbow extension to move them backward. These elbow flexion to move the rear wheels forward, and shoulder extension and elbow flexion to move the rear wheels forward and shoulder flexion and elbow extension to move the rear wheelie balance, subjects used a pattern characterized by shoulder flexion and elbow extension to move the rear wheel and then quickly rolled forward. One subject started go of the wheel to reposition their hands over the center of the wheelchair.

In most (16 of 20) of the digitized trials of subjects main-keeping balance, there was little trunk movement while maintaining the wheelie. In addition to the 20 successful trials, we discarded 12 mistrials (9 because the subjects failed to achieve sufficient pop heights, 2 because the subjects pitched too far forward and were unable to maintain the wheelie position, 1 because the subject pitched too far backward to maintain the wheelie).

Relation Between Wheelchair Pitch and Displacement
A representative plot of wheelchair pitch angle and linear displacement against time is shown in figure 2. Qualitatively, there was an inverse relation between the direction of pitch and the direction of linear displacement of the wheelchair in all 20 trials. Although the extent of the changes in pitch and displacement were generally proportional, there were a number of instances when a small change in pitch (<1°) was not associated with a displacement of the wheelchair. Each subject’s mean pitch and displacement data are shown in figure 3. The group mean pitch angle was 13.6° ± 2.3°. The group mean rear-wheel linear position relative to its starting position was 0.0 ± 4.9cm. Subject 5, who was the tallest and had the greatest mass, had the greatest range of pitch and displacement.

Regarding within-subject reliability, correlations between the 2 trials ranged from .65 (p = .043) to .94 (p < .001). The matched-pairs t tests indicated no significant differences between trials 1 and 2 for all variables, except minimum pitch angle (p = .029). After a Bonferroni adjustment, the p value was no longer significant.

Regarding the timing of the changes in pitch angle and the corresponding linear displacements, in 15 of the 20 trials we found a maximum correlation between pitch angle and linear position of the wheelchair at k = 0 on the time-series analysis. In 5 trials, the maximum correlation occurred after a time shift in the data, with the changes in linear position from 1 of 60 to 5 of 60 seconds after the changes in pitch.

DISCUSSION
In a group of moderately skilled, able-bodied subjects quickly maintaining a stationary wheelie, the reactive balance strategy hypothesis was refuted. Indeed, we found strong evidence of the converse—as the wheelchair pitched in 1 direction, the chair rolled in the opposite direction. In most trials, there was little or no phase lag between these events. However, we do not want to place too much emphasis on the time-series analysis because the videotape data were sampled at 60Hz (1 of 60s), which would not be high enough to detect very brief phase lags (ie, in the reflex range).
Kauzlarich and colleagues\(^3,^4\) noted a forward-backward cyclic motion during wheelee performance and interpreted this as the subjects overshooting the balance point, requiring corrections in the opposite direction. They suggested that this was a form of “Bang-Bang”\(^15\) control. Such an interpretation assumes that the movements are reactive in nature. We saw evidence of such a reactive strategy during training. Indeed, to wheel forward or backward 1 meter in the wheelie position requires that the wheelchair user allow the COM to fall in the direction of the intended travel and then to catch up with the BOS. However, we did not observe the reactive strategy during any of the 20 digitized trials of stationary wheelies.

The 3 types of postural control synergies for standing balance mentioned earlier (ankle, hip, step strategies) are reactive. However, when a perturbation is expected, the person can use proactive or anticipatory actions to maintain standing balance. In such a situation, one’s ability to maintain posture depends on the nervous system to predict perturbations based on context and experience.\(^16\) Hass et al\(^17\) studied developmental aspects of proactive standing balance; they determined that, as children mature, they begin to take advantage of feed-forward (proactive) control. Children younger than 4 years of age could not anticipate perturbations, but as the children’s ages increased, they used proactive postural adjustments more efficiently. Hass\(^17\) also pointed out that children use a rocking motion when standing quietly and hypothesized that this may be a method of calibrating the proprioceptive system.

Maintaining balance during a stationary wheelee in the way that we have documented also appears to be a proactive strategy. The COM and the BOS oscillate about the equilibrium point of the system while in a state of dynamic equilibrium. This reciprocal motion could be advantageous to the wheelee user for various reasons. Wheelee equilibrium is an example of metastability where any small deviation from the equilibrium point will cause the wheelchair to fall.\(^14\) But if the perturbations (forward and backward pitch) are known, the person may be able to prevent the perturbation by using the rhythmic pattern we have described. It may be less costly (in energy and attention) and more effective to rock gently back and forth from one mildly unstable position to another than to sit still and wait for the inevitable fall and then to react to it. This could be especially relevant when individuals with slow reaction times are required to maintain balance. Do et al\(^18\) found that the reaction time of people with paraplegia is approximately twice as long as that of people without neurologic impairments. Such people would be expected to have difficulty maintaining a stationary wheelee if they were relying solely on their ability to react to perturbations.

In the proactive wheelee strategy, the wheelee performer may be using a functional (or virtual) BOS that is larger than the geometric BOS. This functional BOS would provide the wheelee user with a larger area in which to maintain balance. In standing balance, the geometric BOS is defined by the area within the outer boundaries of the feet, but the functional BOS is smaller than the geometric.\(^19\) In wheelee balance, the geometric BOS is very small in the anteroposterior direction. When the BOS translates in the way that we have shown, the functional BOS is larger than the geometric BOS.

One limitation of this research was the small sample size; however, it was adequate to refute the hypothesis. Another limitation was the use of young able-bodied individuals rather than wheelchair users. Some differences in balance and reaction time exist between able-bodied and individuals with disabilities.\(^18,^20\) Factors such as the subject’s age and the nature of the impairments that led to wheelchair use can affect balance differently. Bernard et al\(^20\) provided evidence that differences in sitting balance and stabilization capabilities exist between able-bodied people and those with paraplegia, and that the level of the lesion will further affect the capabilities of the latter group. We elected to use able-bodied subjects for convenience, because we wanted to have control over the amount of wheelee experience subjects had and because we wanted to avoid confounding variables from the neuromuscular impairments that lead to wheelchair use. Nevertheless, the proactive strategy will need to be validated among actual wheelchair users. Also, use of a single wheelchair limits the generalizability of the results.

**CONCLUSIONS**

Subjects maintaining a quiet stationary wheelee use a type of balance strategy that has not been previously described. The characteristic of this strategy is the simultaneous change in wheelchair pitch angle and rear-wheel position such that forward pitch is accompanied by rearward wheel movement and rearward pitch by forward wheel movement. This strategy appears to be proactive and may represent an attempt by the wheelee performer to use a functional BOS that is greater than the geometric BOS. This finding has significance for people learning to perform wheeleys and also sheds new light on the nature of dynamic balance in metastable conditions.

**Acknowledgments:** We thank Dr. John Kozezy, Steve LeBlanc, and Wade Blanchard for their assistance.

**References**


 Suppliers
a. Model PRO-T; Action Technology, A Division of Invacare Corp, North Ridgeville, OH 44039.
b. Model # VM-2400A; Hitachi (HSC) Canada, Inc, 330 Trans Canada Hwy, Point Claire, Que, H9R 1B1, Canada.
c. Peak 5 Analysis System; Peak Performance Technologies, 7288 Revere Pkwy, Ste 603, Englewood, CO 80112.