Development of Valid and Reliable Measures of Postural Stability

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Abstract

Background/Objective: The development of simple postural stability tests that relate to performance of activities of daily living (ADL) and can be quickly performed in a clinical setting may assist clinicians in determining appropriate wheelchair configurations and postural supports in an efficient manner. The study's purpose was to validate 3 clinical measures of reach—functional reach (FR), reach area (RA), and bilateral reach (BR)—against the performance of ADL tasks.

Methods: Two groups of 20 subjects differing by time since spinal cord injury were tested. Three measures of reach—FR, RA, and BR—were recorded with and without permitting compensatory strategies. Subjects also attempted a series of ADL tasks. Group 2 subjects participated in test-retest reliability of the reach measures and to measure reach while using compensatory strategies. Correlation, ANOVA, and linear regression were used for analysis.

Results: Regression analysis showed that injury level was a significant predictor of success in performing ADL tasks (%ADL). Significant but not strong correlations were found between %ADL and all uncompensated reach measures. Within Group 2 subjects, compensated FR ($r = 0.663$) and RA ($r = 0.647$) were more related to the %ADL score than the uncompensated FR ($r = 0.348$) and RA ($r = 0.305$) measurements. BR had the strongest relationship with %ADL scores ($P = 0.031$) and was the only significant uncompensated reach measurement within the regression analyses.

Discussion and Conclusion: While working with clients on seated stability and functional movement, clinicians should be encouraged to incorporate BR tasks because it has the strongest relationship to ADL performance. Researchers interested in studying postural control and stability during functional tasks should consider using uncompensated reach measures.

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INTRODUCTION

The ability to efficiently perform functional activities from a wheelchair is critical for a productive lifestyle. Adequate seated stability and trunk control is required to perform

upper extremity (UE) movements necessary for activities of daily living (ADL). Wheelchair users with decreased or absent trunk control exhibit impaired sitting balance and stability (1–16). A natural conflict exists between the need for trunk stability and the need for trunk mobility to allow performance of UE tasks.

For example, persons who require external support for trunk stability may not be able to reach in lateral directions due to the restrictions of the trunk supports, resulting in less functional trunk mobility. Wheelchair users and clinicians attempt to balance stability and mobility through posture, wheelchair set-up, and seating systems to optimize performance of functional activities for the wheelchair user.

Hobson and Toombs (1) found that people with spinal cord injury (SCI) who have diminished trunk

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control tend to assume a posterior tilted pelvis and a kyphotic thoracolumbar spine in sitting to seek stability. This finding was corroborated by Sprigle et al (17), who found that reach measures were affected by the seated posture adopted by subjects with SCI.

Posture and postural stability are commonly addressed by education in proper alignment while seated, balance training, and the configuration of the seating system. Most wheelchairs on the market are capable of a wide range of adjustments based on a person's specific needs, including seat angle, backrest angle, seat depth, and back height. Numerous research studies have related wheelchair configuration to spinal alignment (2,18–21) and have explored how different wheelchair configurations affect seated interface pressures and the risk of pressure ulcers (1,18,22–25). Several studies have investigated the effect of wheelchair configurations or seating systems on reach and UE functional tasks. These studies found results differed depending on the task and the configuration used in the study (2,7,15,18,26–28).

Janssen-Potten et al (7) found no differences in active reaching during a bimanual activity in persons with SCI and nondisabled controls while sitting in chairs with 4 configurations of tilt and recline. Findings also showed that sitting balance measured by center of pressure (COP) displacement improved in all chair configurations relative to a standard chair except in the high SCI group. The same authors also determined that a 10° forward seat inclination did not affect balance control in persons either with or without SCI during a bimanual reach activity (2). Hastings et al (18) found that persons with complete SCIs exhibited a more erect posture and a greater vertical reach ability while sitting in a wheelchair with posterior seat inclination, low backrest height, and acute seat-to-back angle (clinically referred to as “squeeze”) compared with standard wheelchair configurations. Sprigle et al (17) found that forward reach distance and unilateral reach area (RA) was not affected by cushion type or backrest height in persons with SCI.

In contrast, Aissaoui et al (28) used targeted reaching and measured COP in a study of wheelchair users with paraplegia. While reaching toward targets placed at 45° from the midsagittal plane to the ipsilateral and contralateral sides, sitting balance as measured by COP displacement and COP velocity was significantly improved when subjects sat on a generic contoured foam cushion vs a flat foam or air flotation cushions. Amos et al (27) studied elderly wheelchair users and determined that a solid seat insert with an anterior wedge cushion vs a sling seat improved forward reaching using a goal-directed activity. Lateral reach distance, however, was not improved with a solid seat insert and wedge.

Two studies examining the effect of wheelchair configuration on performance of functional activities other than reach reported equivocal results. In a group of wheelchair users with recent SCI, May et al (29) evaluated the performance of functional tasks (timed

forward wheeling, ramp ascent, 1-stroke push, and forward vertical reach) using 3 types of wheelchair backs. They found that, aside from reaching, the back support did not significantly affect the performance of functional activities. In addition, the subject's wheelchair back preference did not consistently match best performance. Bolin, Bodin, and Kreuter (26) compared changes in seating and wheelchair configuration of 4 wheelchair users with C5-C6 tetraplegia on 8 different variables: balance, transfers, wheelchair propulsion, wheelchair skills, physical strain, spasticity, respiration, and perceived changes by the subjects. They found that the variables tested were affected by the sitting position in an individual manner and that not 1 standard solution worked for all. The results of these studies were corroborated by Sprigle et al (17), who concluded that individuals may perform better with a particular seating system but that no single seating system is best for all people.

Because wheelchair configuration must be matched to each individual, clinicians who perform wheelchair evaluations have the responsibility of determining the appropriate wheelchair configuration and seating system to promote optimal function from each individual wheelchair user. This is especially true of new users who have yet to acquire the necessary wheelchair experience to provide their own input. Back height, seat to back angle, the slope of the seat, and the type of seating components may impact a person's ability to function from the wheelchair. Most of the time, the angles, heights, and placement of secondary supports can be easily changed to improve a person's balance and function.

Numerous wheelchair skills tests have been developed to assess the functional ability of people using their wheelchairs. Kilkens and Post (30) reviewed 24 measures and found many to be comprehensive yet time consuming because some measures require up to an hour to administer. The skills most frequently included in the tests were wheelchair propulsion, transfers, negotiating curbs and ramps, and traversing tracks. These tests are specific to manual wheelchair users. Only 8 of the 24 tests included ADL tasks. This may be because measuring ADL tasks requires the greatest time commitment and most equipment. The time to complete these wheelchair skills tests may be prohibitive in an evaluation setting if multiple adjustments to the chair are necessary to maximize performance, especially if the tests need to be repeated to determine positive change.

The development of simple postural stability tests that relate to ADL performance and can be quickly performed in a clinical setting may assist clinicians in determining appropriate wheelchair configurations and postural supports in an efficient manner. This study's purpose was to validate 3 clinical measures of reach against the performance of ADL tasks. One objective was to determine if 1 or more reach measures could serve as a

Table 1. Level of Injury Distribution Per Group

	Level of Injury	Number of Subjects
Group 1	C5-C6	4
	C6-C7	6
	T1-T7	5
	T7-S1	4
Group 2	C5	1
	C6-C7	10
	T1-T6	5
	T7-T12	4

clinical tool that reflects postural control and stability when performing functional tasks. A better understanding of this relationship can inform clinicians and researchers about the utility of reach measures within wheelchair and seating evaluations and can facilitate research into functional activity. Other objectives were to study the influence of injury level, time since injury, and pelvic tilt on reach and ADL performance.

These objectives were met by addressing 4 hypotheses:

1. Clinical measures of reach are correlated with ADL performance
2. Use of compensation during clinical reach tests has the same correlation to ADL performance as uncompensated reach.
3. Subjects injured for approximately 6 months or less achieve the same reach distances and ADL performance as subjects injured for more than 1 year.

4. Pelvic tilt is significantly related to reach measurements and ADL performance.

METHODS

Subjects

The study consisted of 2 subject groups (Group 1 and Group 2) that differed in time since SCI; 20 subjects with paraplegia and tetraplegia secondary to traumatic SCI were recruited into each group. Data from one Group 1 subject were not included in analysis after the discovery that he did not fully meet inclusion criteria. Data from Group 1 consisted of 10 subjects with tetraplegia and 9 subjects with paraplegia. Group 2 consisted of 11 subjects with tetraplegia and 9 subjects with paraplegia (Table 1). Time since injury varied between groups. Subjects in Group 1 were near or greater than 12 months post injury, ranging from 11 to 242 months (median = 51.5 mo). One year post injury was targeted to allow enough time to maximize ability to perform functional tasks. These subjects were recruited through a convenience sample of outpatients in the seating clinic at Shepherd Center. Subjects in Group 2 were recruited from a convenience sample from the SCI day program at Shepherd Center. Days post injury of Group 2 subjects ranged from 41 to 213 days (median = 101.5 d). Subjects injured approximately 6 months or less were targeted to adequately distinguish Group 2 from Group 1. Exclusion criteria for both groups included orthopedic and neurological conditions that preclude UE reaching and ADL activity. As a result, most individuals with injuries at the C5 level and above were excluded due to a lack of wrist extension. The existence of pressure ulcers also excluded potential participants, if pressure ulcers limited seating time to less than 2 hours.

Figure 1. The functional reach (FR) measure. (a) Starting position. (b) Subject reached as far forward as possible without losing balance.

Figure 2. The reach area (RA) task is a unilateral task that measures the total area encompassed while reaching in lateral, forward, and contralateral directions. (a) Subjects reached in a random order as far as possible without losing their balance in 4 directions and the maximum distance reached was recorded. (b) The measurements defined as RA. During reach, subjects placed the contralateral hand on the umbilicus to negate UE compensatory stabilization.

Subjects in Group 1 ranged in age from 15 to 58 years (median = 33 y) and included 16 males and 4 females. Group 2 subjects ranged in age from 16 to 32 years (median = 23.5 y) and included 15 males and 5 females. Groups 1 and 2 included both manual and power wheelchair users. Group 1 had 15 manual chair users and 4 power chair users, and Group 2 had 19 manual chair users and 1 power chair user. All subjects used their own wheelchairs and seating systems. All subjects reviewed and signed informed consent forms approved by the Shepherd Center Research Review Committee.

Measures

The functional reach (FR) measure is a unilateral forward reach previously described in the literature (17,31,32). A sliding peg was mounted on a horizontal bar mounted to a tripod. The starting position of the peg was placed at the end of the flexed hand as an investigator passively extended the dominant UE with the subjects back against the backrest of the wheelchair (Figure 1a). Subjects were instructed to reach as far forward as possible without losing balance (Figure 1b). This distance was recorded as FR. The contralateral hand was placed on the umbilicus, negating any UE compensatory stabilization. Three trials were recorded with the median entered into the analysis. FR reliability from a test chair has been previously reported as 0.870 (17).

RA is a unilateral task that measures the total area encompassed while reaching in lateral, forward, and contralateral directions (15,17). A digital tape measure secured to a tripod was placed in front of the subject, far enough away so as to not interfere with a forward reach. A tape measure was secured to the subjects' wrists on their dominant UE, and the tape measure was zeroed out with the subjects sitting upright in the wheelchair, their back against the backrest of the wheelchair, and their reaching arm flexed forward 90°. Subjects were instructed to reach in a random order as far as possible without losing their balance in 4 directions: laterally (0°), diagonally to the ipsilateral side (45°), forward (90°), and across their bodies (135°), and the maximum distance reached was recorded (Figure 2a). The area encompassed by these reaches was calculated using a trigonometric algorithm, and this area was normalized to the area defined by sweeping the arm through a range of 135° without any trunk rotation or flexion. Figure 2b illustrates the measurements defined as RA. During reach, subjects placed the contralateral hand on the umbilicus to negate UE compensatory stabilization. Three trials were recorded with the median entered into the analysis. RA reliability from a test chair has been previously reported as 0.902 (17).

Bilateral reach (BR) measures the maximum forward distance that the subject can perform during a bilateral

Figure 3. Bilateral reach (BR) task measures the maximum forward distance that the subject can perform during a bilateral task without loss of balance. Subjects depressed switches positioned in front of each arm. The switches were placed at a minimum forward distance of 70% of arm length and progressively moved outward in 10% intervals.

task without loss of balance (12,17) (Figure 3). Subjects were asked to depress switches positioned in front of each arm with their distances normalized to arm length (measured from acromioclavicular joint to styloid process). Targets were placed at a minimum forward distance of 70% of arm length and progressively moved outward by 10%. The task was to sequentially depress each of the switches for 5 seconds, moving from one switch to the next within 1 second. This 1-second time limit between switches ensured that the action was not a sequence of unilateral tasks allowing the subject to use excessive arm swing to prevent loss of balance. Results were the final normalized distance at which successful completion was achieved without loss of balance. BR has been found to have a test-retest reliability of 0.905 when performed from a test chair (17).

Functional ADL Tasks.

All subjects were asked to complete a series of ADL to assess whether the reach measures (BR, FR, RA) were predictive of everyday function. A series of ADL tasks were identified using interviews with clinicians and patients at 2 rehabilitation hospitals. The challenge was to identify a cohort of activities that reflect balance and stability without a significant strength or grip requirement. In order to mimic real-world scenarios, subjects were allowed to complete the ADLs using any strategy they preferred, and compensations were recorded. Each task was assigned a point value depending on success of task and the assistance required. Task scoring followed the

guideline that full points were awarded if a task was completed without UE stabilization or compensation.

Subjects were guarded by an investigator to prevent falls in case balance was lost. A single investigator scored all ADL tasks for all subjects while observing the subjects' performances. The ADL tasks were videotaped for reference if needed.

Tasks

1. Typing on a keyboard. Subjects were scored by their ability to type bilaterally (2 points) or unilaterally with or without bracing by contralateral UE (1 point). Subjects with poor hand function were fit with a universal cuff and small pointer to depress keys.

2. Operating kitchen appliances. Subjects were asked to operate 3 common appliances (microwave, dishwasher, and oven) and were judged by their abilities to complete 3 tasks: operation of the door, loading an item, and operation of controls. Successful completion of each task was awarded 1 point if performed with UE assistance and 2 points if performed without UE assistance for a total of 6 possible points for each appliance.

3. Turning faucet on/off. Subjects were awarded 1 point to successfully operate the faucet lever and 1 point to wash and rinse hands for a maximum of 2 points.

4. Accessibility guidelines reach. Subjects were asked to perform reaches to the heights defined in the Uniform Federal Accessibility Standards (1988). Heights are defined from the floor for 2 approaches for placement of outlets, light switches, etc.

1. Forward approach: 15-inch minimum low reach and 48-inch maximum high reach
2. Parallel approach: 9-inch minimum low reach and 54-inch maximum high reach

Three points were awarded for reaching without any UE use; 2 points were awarded for reaches that required UE assistance. A total of 12 points could be awarded for this task.

5. Operate an elevator. Subjects were required to maneuver their wheelchairs into an elevator, position their wheelchairs in the elevator, and operate both the door (1 point) and floor button controls (1 point).

6. Pressure relief. Subjects performed lateral, forward or push-up movements. After both observing the movement and using a pressure monitor, the investigator awarded 1 point for a successful pressure relief maneuver. A successful pressure relief maneuver was defined as a 50% pressure reduction under the buttock area.

7. Moving box. Subjects were asked to move a 1-lb cereal box from one side of the body to the opposite side. A small barrier was placed on the table to require the subject to pick up and control the box. Successfully moving the box in both directions (right to left and left to right) was worth 2 points; successfully moving the box in only one direction (eg, from R to L) received 1 point.

Table 2. Correlations Between ADL Scores and Reach Measures

	FR	RA	BR
%ADL	0.468	0.434	0.583
	(<i>P</i> = 0.0031)	(<i>P</i> = 0.0061)	(<i>P</i> = 0.000)

8. Dressing while in wheelchair. Subjects performed this bilateral task by donning and doffing a jacket and a pull-over shirt. One point was assigned for each garment donned, and 1 point was assigned for each garment doffed, for a total of 4 points if this task was done with complete success.

9. Eating with a fork. Subjects used a fork to bring food to their mouths (1 point).

10. Retrieving a small box from floor. Subjects were instructed to retrieve a small box placed on the floor in front of the footplate(s). Three points were assigned if task was completed without contralateral UE support, 2 points if UE support was used, and 1 point if the trunk was flexed forward and stabilized on the thighs in order to reach.

11. Operating a wall-mounted telephone. Subjects who successfully managed a handset and keypad were assigned 2 points if accomplished without UE stabilization and 1 point if stabilization was required.

12. Open and shut door. Subjects who successfully opened and shut a lever-operated door without UE assistance were awarded 2 points each to open and shut the door and 1 point in either direction if UE assistance was used. A maximum of 4 points was possible.

The maximum attainable score for the ADL tasks was 53 points. Each subject's ADL scores were added together and then divided by 53 to determine their percent ADL score (%ADL).

Procedure. Each participant's seating system was recorded with respect to the type of chair and cushion, back and seat angles, and back height and type. Pelvic tilt was recorded using a pelvic goniometer (33) for all subjects prior to initiating any test procedures. Three measures of reach—FR, RA, and BR—were performed in a randomized order for all subjects. A series of practice trials were performed to allow subjects to gain comfort with all of the reach measures. Subjects were then asked to complete a series of tasks that reflected typical ADL. These tasks were performed in a randomized order.

Group 1 subjects were recruited for 1 90-minute

session, during which reach measures and ADL tasks were recorded. Group 2 subjects were recruited for 2 60-minute sessions to permit assessment of test-retest reliability of the uncompensated reach measures and to measure reach while using compensatory strategies. In the first session, subjects in Group 2 performed the clinical reach measures of postural stability with and without compensations. Prior to reach measurements in which compensation was allowed, subjects were instructed to perform the tasks using any method desired, including use of a contralateral UE for support or change in seated posture. During Group 2's second session, reach measures were repeated without compensation for test-retest reliability and ADL tasks were performed.

The different approach to subject scheduling and management was done for logistic and scientific reasons. As outpatients, Group 1 subjects had to travel for testing, so a single visit was advantageous and minimized subject burden. Investigator experience led us to limit testing to 90 minutes to prevent fatigue and disinterest. Group 2 subjects, as day program patients, did not have to travel specifically to participate; therefore 2 sessions were used, which enabled test-retest and compensatory testing without violating the session length goal.

Data Analysis. Median values of reach measures were entered into analysis. Investigators selected median as a more stable measure of central tendency for 3 trials. The %ADL was calculated for each subject and used in the analysis.

Intraclass correlation coefficients (ICC) and repeatability coefficients were calculated to determine test-retest repeatability of uncompensated reach measures using the repeated measurements of Group 2 subjects. Although repeatability of these measures has been shown when being performed from a test chair (17), this analysis was repeated because subjects used their own wheelchairs within this study. Significance of the ICCs was determined by values reported by Currier (34): <0.69 as poor; 0.7–0.79 as fair; 0.80–0.89 as good, and 0.90–0.99 as excellent.

Correlations were calculated to determine the relationships between reach measures and ADL score, between pelvic tilt and reach measures, and between pelvic tilt and %ADL scores. A general linear model was used to perform analysis of variance (ANOVA) on reach measures across group and injury level and differences in ADL scores across time since injury (Group 1 or 2) and injury level (paraplegia or tetraplegia). Linear regression

Table 3. Correlations Between Pelvic Tilt and Reach and ADL Scores

	FR	RA	BR	%ADL
Pelvic tilt	0.315	0.176	0.127	0.096
	(<i>P</i> = 0.061)	(<i>P</i> = 0.305)	(<i>P</i> = 0.460)	(<i>P</i> = 0.577)

Table 4. ANOVA Comparison of Groups 1 and 2

	Mean (SD) Group 1	Mean (SD) Group 2	P Value
FR	0.219 (0.147)	0.243 (0.123)	0.569
RA	0.953 (0.331)	0.971 (0.395)	0.868
BR	143 (42.8)	116 (40.8)	0.033
%ADL	0.707 (0.167)	0.628 (0.169)	0.083

analysis was used to identify significant predictors of ADL scores using 2 approaches. One approach included the reach measurements, injury level, and group as predictors of %ADL. The other approach entered only reach measures as predictors of %ADL.

Correlation and regression analyses were also run to compare compensated to uncompensated reach measures and their respective relationships to %ADL. Because only Group 2 subjects were asked to perform both compensated and uncompensated reach, the analysis was restricted to these 20 subjects only.

MiniTab 14 was used for all statistical analysis. Significance values for all analyses were recorded with levels less than or equal to $P = 0.1$ being presented and discussed.

RESULTS

Test-retest repeatability was demonstrated as fair to good for all 3 reach measures. The ICCs were as follows: FR = 0.858, RA = 0.705, and BR = 0.725. For FR, 5 of 20 Group 2 subjects recorded higher values during day 1 measurements. For RA, 9 of 20 subjects recorded higher values during day 1 measurements. For BR, 6 of 20 subjects recorded higher values during day 1 measurements.

Correlations

The relationships between %ADL and reach measures achieved significance with only BR exceeding $r = 0.5$ (Table 2). Most subjects sat with a posterior pelvic tilt with a median angle of 23.5° (range: 16° anterior tilt to 47° posterior tilt). Pelvic tilt had a significant but clinically weak relationship to FR. Pelvic tilt had poor relationships to the other reach measures and %ADL scores (Table 3). ANOVA. When analyzing uncompensated reach with respect to time since injury, only BR was significantly different in Group 1 vs Group 2 subjects (Table 4). All 3 reach measures were significantly higher in subjects with

thoracic or lumbar injuries compared with those with cervical level injuries (Table 5). %ADL scores were higher in Group 1 subjects, but the difference was moderate ($P = 0.083$) (Table 4). The interaction between group and injury level was not significant for any variable. Subjects with thoracic or lumbar injuries had, on average, 35% higher %ADL scores compared with subjects with cervical injuries ($P = 0.00$). Subjects injured longer achieved a 12.5% higher %ADL score (Table 4).

Regression. When all 5 variables (3 reach measures, time since injury, and injury level) were entered into the analysis, injury level ($P = 0.004$) was a significant predictor of %ADL and explained 43% of %ADL variability. When only the reach measures were entered as predictors, only BR was a significant predictor ($P = 0.031$) and explained 29.4% of the variability in %ADL scores (Table 6).

Analysis of Compensated and Uncompensated Reach Measurements. Analysis of only Group 2 data resulted in different correlation values than when both Groups 1 and 2 were added into the analysis. Significant relationships existed between %ADL and compensated reach measures (Table 7). Relationships of FR and RA with compensation are much higher than the relationships without compensation. BR measures were significantly related to %ADL in both situations. BR relationships remain stable regardless of compensation because BR is a bilateral task and cannot be done while stabilizing with the UE.

Regression analysis included recalculation of uncompensated reach measurements using only Group 2 data and analysis of the reach measurements using compensation. Regression using all compensated reach measures and injury level (Table 8) resulted in 2 significant predictors of %ADL: injury level ($P = 0.024$) and compensated FR ($P = 0.002$). The resulting equation had an R -squared value of 0.589. Entering only the 3 compensated reach measurements resulted in an

Table 5. ANOVA Comparison of Injury Level

	Mean (SD) C-Level Injury	Mean (SD) T/L Level Injury	P Value
FR	0.189 (0.070)	0.285 (0.175)	0.024
RA	0.808 (0.182)	1.16 (0.436)	0.002
BR	112 (35.7)	151 (43.7)	0.005
%ADL	0.577 (0.156)	0.782 (0.110)	0.000

Table 6. Regression Analysis of Uncompensated Reach Measures, Injury Level, and Group

Regressor	Predictors	Significant Predictors	Explained Variance
%ADL	FR, RA, BR, injury level, group	Injury level ($P = 0.004$)	43%
%ADL	FR, RA, BR	BR ($P = 0.031$)	29.4%

equation with R -squared equaling 0.439 with compensated FR as the only significant predictor ($P = 0.001$). Regression was repeated using injury level and uncompensated reach measures (FR, RA, and BR) from Group 2 subjects only. Only BR was a significant predictor ($P = 0.014$) of %ADL, and the resulting equation explained 29% of the %ADL scores. BR was also the sole predictor of the regression with combined Group 1 and 2 data, as indicated above.

DISCUSSION

The results can be applied to both clinical and research situations. Both situations require repeatable measurements to gain assurance that a reach measure performed one day would relate to the same measure taken another day. However, research and clinical applicability differ with respect to purpose and how such issues as internal and external validity influence the interpretation of results.

Test-retest repeatability was lower within this study than previously reported (17), but all 3 reach measures achieved an acceptable level of repeatability. This study measured reach while subjects were seated in their own wheelchairs, with variation in the seating configurations and cushions used. Reach measurement while subjects were seated in their own wheelchairs is reflective of a clinical measurement because clinicians can perform these tests during a wheelchair and seating evaluation.

Subjects sat in many different postures, with about 90% sitting in $>10^\circ$ of posterior pelvic tilt. Previous research on reach in subjects with SCI indicated that injury level and pelvic tilt were significant predictors of FR (17). This study found pelvic angle to have a significant correlation with FR, but that this relationship was not clinically strong ($r = 0.315$). Pelvic tilt was not related to performance of ADLs.

Several differences across groups and injury levels were identified. As expected, all reach measures and %ADL scores were higher within subjects with paraplegia compared with those with tetraplegia. Regression analysis showed that injury level was a significant predictor of

%ADL, further corroborating the functional influence of level of SCI. The ability to control the trunk and UEs during reach and activity is apparent within these results. Differences between the time since injury groups were less distinct. Only BR showed significance based on ANOVA, with a difference of 23% between Groups 1 and 2. Subjects who had been injured for more than a year were better able to perform this BR task than those with newer injuries. The ANOVA identified a difference in %ADL scores, with Group 1 scores being slightly higher at 71% vs 63% for Group 2. Perhaps a higher number of subjects would have better distinguished between the 2 groups. Both Groups performed the FR and RA tasks equally well. These results may be used to inform rehabilitation interventions. While working with clients on seated stability and functional movement, clinicians should be encouraged to incorporate BR tasks.

The influence of functional compensation techniques is illustrated in the correlation results between the reach measures and %ADL scores. The correlations between %ADL and uncompensated reach for all subjects (Groups 1 and 2) indicate that FR, RA, and BR are significantly correlated but the relationship is not particularly strong (Table 2). This result is consistent with the fact that ADL tasks were performed using myriad compensatory techniques. Examples of compensation while performing the reach or ADL tasks included holding onto the wheel or armrest, hooking onto the backpost/push handle, holding on the front hanger of the wheelchair, and bending forward and resting the trunk on the thighs. As expected, subjects approached these tasks in many different manners according to their functional abilities, confidence, and prior experience. Within Group 2 subjects, FR ($r = 0.663$) and RA ($r = 0.647$) measurements taken while subjects compensated for stability or balance limitations were more related to the %ADL score than the uncompensated FR ($r = 0.348$) and RA ($r = 0.305$) measurements. Regression analysis of the compensated measures identified compensated FR as the best predictor of %ADL score, although the equation showed only moderate predictive validity (R -squared = 0.439). Be-

Table 7. Correlations Between ADL Scores and Compensated and Uncompensated Reach

	FR-Comp	FR-Uncomp	RA-Comp	RA-Uncomp	BR-Comp	BR-Uncomp
%ADL	0.663 $P = 0.001$	0.348 $P = 0.133$	0.647 $P = 0.002$	0.305 $P = 0.192$	0.503 $P = 0.024$	0.540 $P = 0.014$

Table 8. Group 2 Regression Analysis

Regressor	Predictors	Significant Predictor(s)	Variance Explained
%ADL	Compensated FR, RA, and BR and injury level	Injury level; compensated FR	59%
%ADL	Compensated FR, RA, and BR	Compensated FR	44%
%ADL	Uncompensated FR, RA, and BR and injury level	Uncompensated BR	29%

cause of this improved relationship to function, the use of compensated RA and FR appear indicated from a clinical perspective. However, use of self-selected compensation during measures of reach add an unacceptable level of variability within a research methodology studying postural stability and control because subjects use different reach strategies and different UE stabilization techniques that mask measurement of trunk control.

Of the uncompensated reach measures, BR had the strongest relationship with %ADL scores and was the only significant reach measurement within the regression analyses of the combined and Group 2 data sets. BR was the most lengthy of the reach measurements but showed good application from both clinical and research perspectives.

Limitations of this study include taking measurements using the subject's own wheelchair and seating system, as well as a self-selected posture. Although this approach added variation across subjects, the decision was purposeful because it best represents a clinical setting during which individualized wheelchairs, seating systems, and postures are utilized. Relatedly, the types of compensation used were also self-selected. Another limitation was that seated posture was only characterized by a measure of pelvic tilt. Further description of posture, such as kyphosis and pelvic obliquity, may have identified a postural relationship to reach and ADL performance.

CONCLUSION

The reach measures were selected because of their inherent differences. FR is a unilateral, sagittal plane activity that requires antero-posterior postural control. RA is also a unilateral task but requires control in both the sagittal and horizontal planes. BR required both UE movements and, therefore, was not sensitive to UE compensatory techniques. Because of these differences and the results of this study, a few inferences can be made.

People who have been injured longer, regardless of level of injury, were able to reach farther with bilateral UE. Because stabilization with an UE is not possible with a bilateral task, this finding implies that balance training while incorporating BR tasks during initial rehabilitation may lead to success more quickly.

Clinicians who seek a simple clinical measurement of reach can use one or all of these reach measures during

wheelchair and seating evaluation. Clinically, compensated FR and RA and bilateral tasks seem to be the most related to ADL performance. The tests can quickly be performed in a clinical setting and can be useful in determining which wheelchair set up best assists the user in performance of daily tasks. In order to better reflect functional stability, clients should be allowed to compensate for balance and stability limitations while performing these tasks. Training in different compensatory techniques may benefit the person with SCI in performing ADL. Researchers interested in studying postural control and stability during functional tasks should consider using uncompensated reach measures. The variability of compensation techniques used by subjects is so vast that relating reach measures using compensation to postural control would be difficult.

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