Effects of an Exercise Program to Increase Hip Abductor Muscle Strength and Improve Lateral Stability Following Stroke: A Single Subject Design

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ABSTRACT

Background and Purpose: Persons with lower extremity weakness following stroke often demonstrate difficulty with weight transfer and paretic lower extremity loading. These deficits, in turn, can lead to problems with lateral stability, or the ability to control movement of the center of mass in the frontal plane. The primary aim of this study was to examine the efficacy of an individualized home exercise program in improving hip abductor muscle strength and lateral stability in a subject with chronic stroke. **Methods**: An A-B-A treatment-withdrawal single-subject design was used. The subject was a 70-year-old male who had experienced a left hemispheric stroke 36 months prior to initiation of the study. Bilateral hip abductor muscle strength, single limb stance (SLS), timed 360° turn, Step Test, and 10-m walk at self-selected and fast speeds were recorded at regular intervals during the baseline (A-1), treatment (B), and treatment-withdrawal (A-2) phases. The home exercise program in the B phase consisted of lower extremity weight bearing and weight transfer activities and exercise on a lateral training device 3 to 5 times a week for 6 weeks. The Berg Balance Scale (BBS) and Stroke Impact Scale (SIS) were administered at the completion of each phase and at 6-week follow-up. Data were analyzed using visual analysis and the split-middle method of trend estimation. **Results:** Mean levels of all measures improved from A-1 to B phases, with significant increases in trend for hip abductor muscle strength and SLS bilaterally. Most improvements were maintained during the treatment-withdrawal (A-2) phase and at follow-up. **Conclusion:** A home exercise program that includes exercise on a lateral training device shows promise for producing increases in hip abductor muscle strength and accompanying improvements in some measures of physical performance and disability in persons with chronic stroke.

Key Words: hip abductors, exercise, lateral stability, stroke

INTRODUCTION

Stroke is a leading cause of serious, long-term disability, affecting about 780,000 people in the United States each year.[1] A majority of those affected are 65 years of age or older.[2] Among those who survive stroke, only 10% recover completely, and many of the remaining survivors need rehabilitation.[3] The economic toll is substantial,[4,5] with an estimated total cost to the Medicare program of $9 billion per year.[5] Postacute rehabilitation services for patients who have had a stroke account for 44% of all Medicare dollars spent on inpatient rehabilitation.[6]

Hemiparesis is the most common impairment observed at 6 months after stroke in those over 65 years of age.[7] Individuals with hemiparesis following a stroke often have difficulty bearing weight on the paretic lower extremity and shifting weight between the two lower extremities.[8-10] These difficulties with paretic lower extremity loading and weight shifting frequently lead to asymmetry in standing and during ambulation, with a greater proportion of body weight distributed on the nonparetic limb than on the paretic limb.[8,10-13] Laufer et al[14] reported that 15 ambulatory subjects undergoing rehabilitation following stroke demonstrated significantly lower weight bearing through the paretic than the nonparetic limb in attempted symmetrical level stance. Placing one foot on a step induced a weight shift to the foot remaining on the floor, but this weight shift was significantly lower when the paretic rather than the nonparetic limb remained on the floor.

Deficits in symmetrical stance and weight shifting abilities do not appear to resolve over time. Despite improvements in motor selectivity of the paretic limb and in balance and walking skills, weight-bearing asymmetry in patients undergoing stroke rehabilitation may persist for at least 3 months after the time patients are first able to stand unassisted for 30 seconds.[15] Both static and dynamic aspects of postural symmetry may remain impaired. In a study by Turnbull et al,[16] 20 subjects who were 16 months to 20 years poststroke and were functionally independent in the community demonstrated significantly smaller ranges of weight shifting in parallel and diagonal stance than comparison group subjects.

The ability to bear weight through both lower limbs and to transfer weight from one leg to the other is critical for moving from sitting to standing (sit-to-stand), for walking, and for all other activities that require lateral stability. Lateral stability is the ability to control the position and movement of the body's center of mass in the frontal plane.[17] Asymmetrical body weight distribution and impaired lateral stability are factors that may contribute to falls in individuals with hemiparesis.[18,19] Fall risk is high both during rehabilitation[18] and after hospital discharge.[20]

The hip abductor muscles appear to play a key role in paretic limb loading and weight transfer and in maintenance of lateral stability following stroke.[10,21-24] Phasic activation of the hip abductors of the flexing limb is of critical importance for mov-

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ing the center of mass over the stance limb when transitioning from bipedal to unipedal stance.[10,21,22] A braking force exerted by the stance limb is necessary to prevent the center of mass from moving too far laterally over the stance limb. Individuals who have regained the ability to walk after stroke exhibit impairments in activation of gluteus medius and hip adductor muscles of the paretic lower extremity during both externally and internally generated lateral weight shifts.[22] These impairments include increased onset latencies and decreased amplitudes of muscle activation in the paretic compared to the non-paretic lower extremity.[22,23]

A variety of interventions designed to improve paretic lower extremity function after stroke have been used in the clinic and examined empirically. Interventions have focused on balance training, lower extremity strengthening, and various combinations of balance, strength, and endurance training. Biofeedback is a common intervention used for balance training. This type of therapy results in decreased lateral sway and more symmetrical weight distribution.[13,16,25-27] Biofeedback has been shown to afford no added benef t compared with conventional therapy, however.[26,27] Furthermore, improvements achieved in standing have not consistently transferred to improvements during gait or other dynamic activities.[13,16]

Interventions focused exclusively on muscle strengthening have been shown to produce signif cant strength gains in subjects with chronic stroke.[28-31] These interventions consisted primarily of exercises designed to enhance force generation through a large range of motion. The researchers emphasized the magnitude of force generation, not the rate of muscle force development. Associated improvements in physical function were limited, perhaps because the exercises were not performed in functional contexts.

Interventions incorporating both balance and strengthening exercises performed in functional contexts have resulted in positive outcomes for subjects with chronic stroke.[32-37] Task-specif c training combined with additional lower extremity strengthening exercises has had particularly promising effects on performance of activities such as sit-to-stand, stepping, and gait. The length of the training program in these studies varied from 3 or 4 weeks[32,33] to 19 weeks.[37] An important limitation of these previous intervention studies is the focus on movement in the sagittal plane and strengthening of muscles that produce sagittal plane movements (hip and knee f exors and extensors, ankle dorsif exors and plantar f exors). The common problem of lateral instability in individuals who are post-stroke, therefore, has not been adequately addressed.

Despite considerable research evidence demonstrating the importance of the hip abductors for lateral stability during functional tasks, including gait, the effects of increasing hip abductor strength have not been investigated in persons recovering from stroke. The primary aim of this study was to examine the efficacy of a home exercise program in improving hip abductor muscle strength and performance of functional tasks requiring lateral stability in a subject with chronic stroke. A secondary aim was to determine whether this type of exercise program shows promise in affecting falls risk (as estimated by Berg Balance Scale score) and/or disability (as measured by the Stroke Impact Scale) in persons with chronic stroke.

METHODS

Design

An A-B-A treatment-withdrawal, single-subject design was used in this study. Tests and measures included bilateral hip abductor muscle strength and the following physical performance measures requiring lateral stability: single limb stance,[30,38] timed 360° turn,[39] Step Test,[40] and 10-m walk at self-selected and fast speeds. Measures were recorded at regular intervals during the baseline (A-1) phase without any intervention, the intervention (B) phase, and the treatment-withdrawal (A-2) phase. A 6-week intervention (B) phase was chosen as providing sufficient time for neuromuscular adaptations to occur in an older adult[41,42] and to accommodate the scheduling restrictions of the researchers. During the intervention phase, the subject performed exercises and functional activities designed to improve amplitude and rate of force development of the hip abductor muscles bilaterally. The Berg Balance Scale (BBS)[43,44] and the Stroke Impact Scale (SIS)[45] were administered at the completion of each phase and at 6-week follow-up.

Subject

The subject was recruited from a list of stroke patients who had expressed interest in participating in educational and research projects at the University of North Carolina at Chapel Hill. He learned about the project when visiting campus for a classroom demonstration, and was the f rst to volunteer. Inclusion criteria were: (1) >1 year poststroke, so that observed changes could not be attributed to neurological recovery, (2) able to stand independently without an assistive device for at least 10 seconds, (3) able to follow a 3-step command, (4) able to walk independently with or without an assistive device for at least 100 ft, (5) unable to perform single limb stance on the paretic lower extremity for more than 5 seconds, and (6) willing to commit to the time requirements of the study and adhere to the prescribed exercise program.

Exclusion criteria were: (1) cardiovascular or musculoskeletal problems that would interfere with performance of a lower extremity exercise program, (2) terminal illness, (3) currently receiving physical therapy, (4) any diagnosed neurological disorder other than stroke, (5) unilateral neglect, as measured by the letter cancellation and star cancellation subtests of the Behavioral Inattention Test (BIT),[46,47] and (6) history of multiple strokes.

The subject was a 70-year-old Caucasian male with a body mass of 98.5 kg and a height of 170 cm (body mass index of 34.1 kg/m^2). He had had a stroke affecting the distribution of the left distal anterior cerebral artery, including the precentral gyrus, 36 months prior to the initiation of the study. He had right hemiparesis immediately after the stroke, but his right upper extremity weakness had largely resolved by the time of discharge from the hospital's inpatient rehabilitation unit at 2 months poststroke. Outpatient physical therapy followed his hospital stay and continued for approximately 18 months. Following rehabilitation, the subject was able to ambulate independently in his apartment and the community using bilateral canes (one quad cane and one single point cane) or a rolling walker. He used a wheelchair in unfamiliar or unpredictable situations. The subject was independent with basic and most instrumental activities of daily living, although he did not drive and needed increased time for many activities. He received occasional assistance from his wife when faced with unusual time constraints.

The subject met all eligibility criteria for the study. He was not receiving any type of therapy services, but walked daily for 30 minutes to an hour with bilateral canes in the morning and a walker in the afternoon. He showed no evidence of unilateral neglect, achieving perfect scores on the letter cancellation and star cancellation subtests of the BIT. Prior to baseline testing, the subject signed an informed consent form approved by the Committee on the Protection of the Rights of Human Subjects at the University of North Carolina at Chapel Hill.

A complete physical therapy examination was performed at the beginning of the baseline phase. The subject's comorbidities included type II diabetes, coronary artery disease, hypertension, hyperlipidemia, and remote history of bladder cancer. His hypertension was well controlled with medication at the time of enrollment in the study. He showed no evidence of dementia, achieving a score of 29 on the Mini-Mental State Examination (MMSE).[48] The subject's score on the lower extremity motor scale of the Fugl-Meyer assessment[49] was 28 out of the maximum 34 points. Manual muscle testing revealed good (4/5) to normal (5/5) strength in the upper extremities, but significant right lower extremity paresis, as well as weakness of left hip extensors and ankle plantarflexors (Table). Range of motion was within functional limits throughout all 4 extremities, except hip internal rotation, which measured 0° on the left and 10° on the right; hip abduction, which measured 20° bilaterally; and ankle dorsiflexion, which measured -5° on the left and 0° on the right. Light touch and pinprick sensations were absent on the medial aspect of the toes, diminished on the medial aspect of the foot to the ankle, and intact proximal to the ankle. Proprioception was mildly diminished in bilateral great toes and intact proximally. The subject stated that his goal for the program was to reestablish mobility of his right lower extremity.

Table. Initial Lower Extremity Manual Muscle Test Grades

Muscle Action	Right	Left
Hip f exion	4/5	5/5
Hip extension (gluteus maximus)	2/5	3+/5
Hip extension (hamstrings)	3/5	3+/5
Hip abduction	3-/5	4-/5
Hip adduction	2/5	4/5
Knee f exion	3+/5	5/5
Knee extension	3+/5	5/5
Ankle dorsif exion	4/5	5/5
Ankle plantarf exion	2+/5	2+/5

Tests and Measures

All physical performance testing was conducted at the subject's place of residence. One of two researchers (VSM, CDW) administered all strength and physical function tests. These two researchers completed 2 one-hour practice sessions at the beginning of the study to help insure consistency in test administration and scoring. The subject wore comfortable clothing and walking shoes for testing, and rest periods were given as needed. Measures were recorded 2 times per week for 3.5 weeks during the A-1 phase, 1 time per week for 6 weeks during the intervention (B) phase, and 1 to 2 times per week for 3.5 weeks during the A-2 phase. The BBS and the SIS were administered by the same examiner (VSM) at the completion of each phase and at 6-week follow-up. The testers began each test session with a blank scoring sheet, with no access to previous test results.

Hip abductor muscle strength

Hand-held dynamometry has been shown to be reliable and valid for measuring muscle strength in individuals with hemiparesis.[50,51] Procedures for measuring isometric muscle strength of the hip abductors in this study were based on those described by Andrews et al.[52] The subject was positioned supine with the hips in neutral rotation. A Chatillon CSD400 dynamometer (John Chatillon & Sons, Inc., Greensboro, NC) was used for measurement of force output during an isometric contraction. This digital strain-gauge dynamometer displays force measurements to the nearest 0.9 N (0.2 lb) to a maximum of 512 N (115.0 lb). The dynamometer was calibrated according to the instruction manual. The dynamometer was placed perpendicular to the thigh, with the padded attachment on the distal lateral aspect of the thigh. The examiner explained the desired muscle action of hip abduction with the knee extended, and allowed the subject to perform one practice trial. A "make test" was used, with the dynamometer held steady and the subject encouraged to push against the dynamometer as hard as possible.[53] After a 2- to 3-second period to allow the subject to build up to a maximal contraction, the force was measured for 5 seconds, and the peak force recorded. After a rest period of at least 30 seconds, a second test trial was performed. The mean of the 2 trials was used for the data point. During all test trials, the subject was given continuous verbal encouragement to push as hard as possible.

Single limb stance[30]

Single limb stance is a reliable clinical measure of balance in older adults with and without disability.[54] A digital stopwatch was used to measure to the nearest hundredth of a second the time that the subject was able to stand on each leg without upper limb support. If the subject was unable to achieve unilateral stance, the time was recorded as 0.00 seconds. Three trials were performed for each leg, and the mean time recorded.

Timed 360° turn[39]

The 360° turn is a component of several standardized balance and physical performance tests,[43,55,56] and the timed version is a reliable measure of dynamic balance.[39,57,58] A digital stopwatch was used to measure to the nearest hundredth of a second the time required for the subject to turn 360° in his preferred direction while standing, using his rolling walker. Instructions were to complete the turn "as quickly as possible." Time was recorded for a single test trial.

Step Test[40]

The Step Test has excellent reliability[40] and evidence of responsiveness to change[59] in individuals with stroke. For this test, the subject was asked to place one foot onto a 7.5-cm high step and then back down to the floor repeatedly as fast as possible for 15 seconds. The number of completed steps for the 15-second test period was recorded. Testing was performed first with the nonparetic leg and then with the paretic leg.

Ten-meter walk

Gait speed is a simple, highly reliable, and responsive measure recommended for assessing outcomes in individuals recovering from stroke.[60-62] A digital stopwatch was used to measure to the nearest hundredth of a second the time required for the subject to walk a 10-m distance using his rolling walker. An additional 5 meters was measured and marked at the beginning and end of the 10-m distance to allow the subject enough distance to accelerate and decelerate. The subject performed one warm-up practice walk at preferred speed as recommended by Green and colleagues.[63] This practice walk was followed by one test trial performed under each of 2 conditions: preferred walking speed and maximum walking speed. For preferred walking speed, the subject was instructed to walk at his "usual, comfortable pace." For maximum walking speed, the subject was instructed to walk "as quickly as possible without feeling unsafe."

Berg Balance Scale (BBS)[43,44]

The BBS has been tested extensively in individuals recovering from stroke, and has been shown to have very strong psychometric properties.[64-67] The BBS was used in the present study as a measure of the subject's ability to maintain balance while performing functional tasks, such as transfers, sit-to-stand, reaching, and turning. The BBS consists of 14 items that are scored on a scale of 0 to 4. A score of 0 is given if the subject is unable to do the task, and a score of 4 is given if the subject is able to complete the task in accordance with the criterion for that task. The maximum total score on the test is 56.

Stroke Impact Scale (SIS) Version 3.0[45,68]

Developed from the perspective of patients, caregivers, and health professionals with stroke expertise, the SIS is a stroke-specific self-report measure of disability and health-related quality of life. The SIS is valid, reliable, and responsive to change in individuals poststroke.[45,68,69] Version 3.0 has 59 items in the following 8 domains: strength, hand function, activities of daily living (ADL)/instrumental activities of daily living (IADL), mobility, communication, emotion, memory and thinking, and participation. The SIS was administered in interview format.

Intervention

Intervention during phase B consisted of an exercise program at the subject's place of residence performed 3 to 5 times per week for 6 weeks. Written medical approval was obtained from the subject's primary care physician prior to the start of the intervention. The exercise program was designed to increase the strength and rate of force development of the hip abductor muscles bilaterally. Each session lasted approximately 30 to 45 minutes and included side leg lifts in sidelying and in standing, sideways lunges, weight shifting in standing, marching in place, progressive bridging, single limb stance, and exercise using a lateral trainer (Dynamic Edge® RPM™, The Skier's Edge Company, Park City, UT).

The lateral trainer has a slide plate that moves side-to-side on a short track, promoting repetitive lower extremity loading and unloading (Figure 1). A balance bar at approximately chest height can be used for upper extremity support. Lateral trainer exercise offers important advantages over treadmill training (with or without partial body weight support), in that it does not require swing phase control. Toe clearance and foot placement do not present problems during exercise on the lateral trainer because the feet remain in contact with the footpads throughout the exercise cycle.

Figure 1. Subject exercising on the lateral trainer in his apartment.

The principle of explosive strength training was applied, with movements executed as rapidly as possible throughout the range of motion.[41] The speed requirements and/or amount of resistance for each exercise were adjusted in accordance with the subject's abilities throughout the intervention phase. The Borg scale[70] and the heart rate reserve (HRR), or Karvonen, method,[71] were used to provide safety guidelines during exercise. In accordance with American College of Sports Medicine (ACSM) guidelines, the training zone was 12 to 16 on the Borg scale. These scale values are considered to approximate 60% to 80% of maximal oxygen consumption.[70,72] The target heart rate for exercise was calculated using the HRR method, with an exercise intensity of 50% to 85% of heart rate reserve. Because the subject was taking beta blocker medication and demonstrated a blunted heart rate response during exercise, the Borg scale was used as the primary method of gauging exercise intensity.

At least one of the researchers was present during 2 of the exercise sessions each week to monitor the subject's progress and to modify the exercises as needed. The subject was taught how to use the Borg scale to determine exercise intensity when the researchers were not present. During each session, the researcher(s) or the subject recorded in an exercise log specific information about the exercises performed (number of repetitions, amount of resistance, duration, etc. as appropriate) and any observations about the subject's responses.

Data Analysis

To address the primary aim of the study, values obtained for muscle strength and physical performance measures (single limb stance, timed 360° turn, Step Test, and 10-m walk) across all 3 phases were plotted and analyzed visually. A "split-middle," or celeration line, approach was used.[73] The celeration line divides the data of each phase into equal halves, with 50% of the data points above the line and 50% below. The effect of the intervention was visually evaluated by assessing change in level or trend of the celeration lines in the A-1 and B phases. A similar assessment was used to examine the effect of withdrawal of the intervention by comparing the celeration lines for the B and A-2 phases. A change in level of the celeration line from one phase to the next indicates variation in average performance on the measured variable, while a change in trend indicates acceleration or deceleration of effect. Statistical signifcance was determined using a binomial test, with the level of significance set at $p < .05$. The slope of the celeration line and the mean value of the measure for each phase also were calculated.

To address the secondary aim, we examined changes in BBS scores and SIS scores from one phase to the next and from the end of the A-2 phase to 6-week follow-up. Likelihood ratios from the literature[74] were used to examine the subject's BBS scores in relation to falls risk.

RESULTS

The subject was able to perform the home exercise program safely and without signifcant muscle soreness or other adverse effects. He exercised 5 days per week for 4 of the 6 weeks and 3 days per week the other 2 weeks, choosing a lower frequency because of a mild viral illness one week and family travel another. He was able to progress the number of sets, number of repetitions, and/or duration of the exercises as instructed by the researchers. On the lateral trainer, he progressed from two 3-minute bouts of exercise to 8 minutes of continuous exercise. The subject never exceeded the exercise guidelines for Borg scale value or heart rate. He stated that the exercises were enjoyable and that he believed they were benefcial for him. By self-report, he performed no exercises other than his regular walking program during the A-2 phase, but resumed most of the intervention exercises following completion of the study (end of A-2) and was still performing these on his own at the 6-week follow-up.

Data and celeration lines for each variable are shown in Figures 2 through 8. A total of 22 data points were collected during the study, 7 in the A-1 phase, 6 in the B phase, and 9 in the A-2 phase. We were unable to test gait speed at one

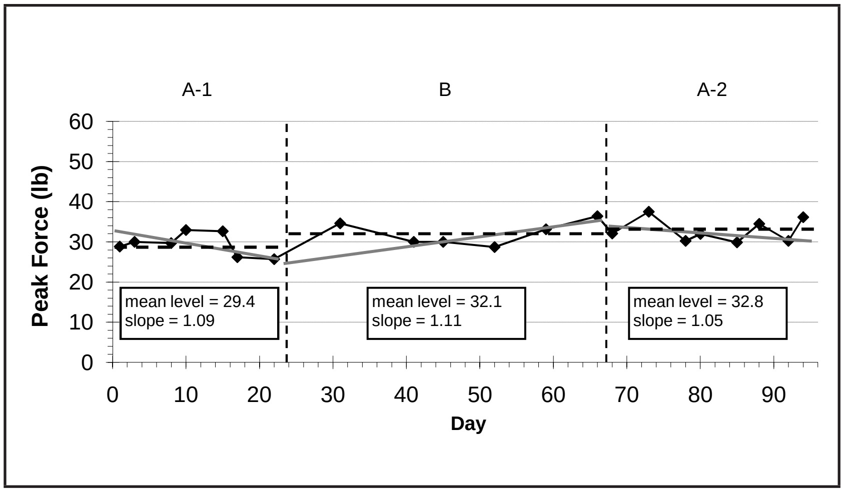

Figure 2. Peak force measurements for the paretic (right) hip abductor muscles during each phase. Celeration lines are solid gray lines. The horizontal dashed lines show the mean level of the variable during each phase.

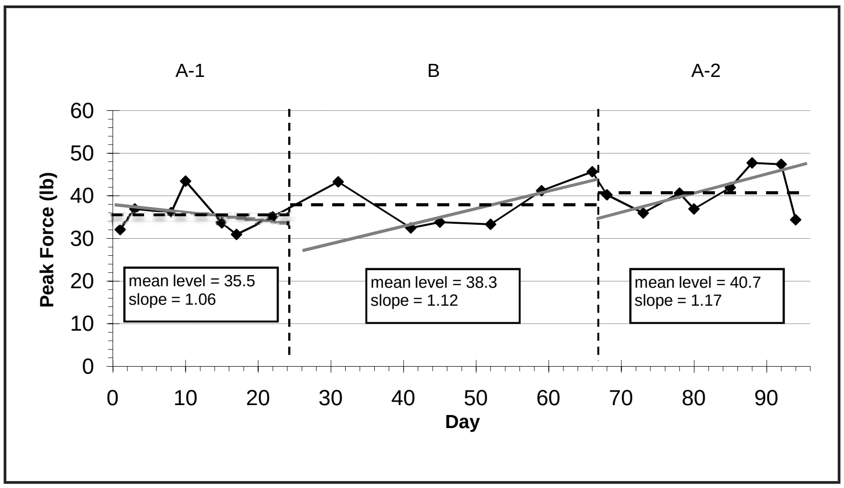

Figure 3. Peak force measurements for the non-paretic (left) hip abductor muscles during each phase. Celeration lines are solid gray lines. The horizontal dashed lines show the mean level of the variable during each phase.

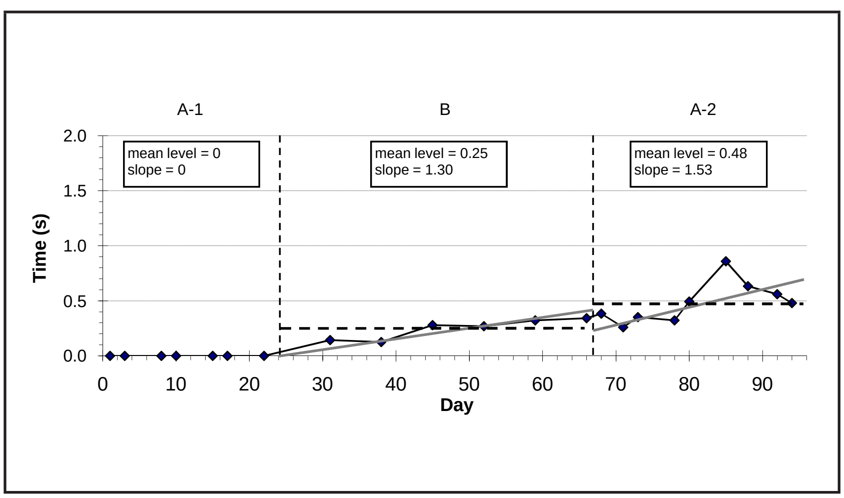

Figure 4. Single limb stance times on the paretic (right) lower extremity during each phase. Celeration lines are solid gray lines. The horizontal dashed lines show the mean level of the variable during each phase.

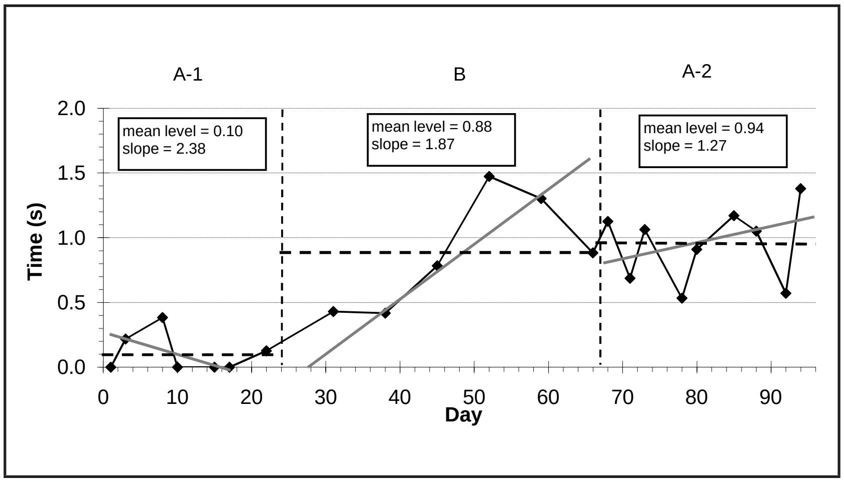

Figure 5. Single limb stance times on the non-paretic (left) lower extremity during each phase. Celeration lines are solid gray lines. The horizontal dashed lines show the mean level of the variable during each phase.

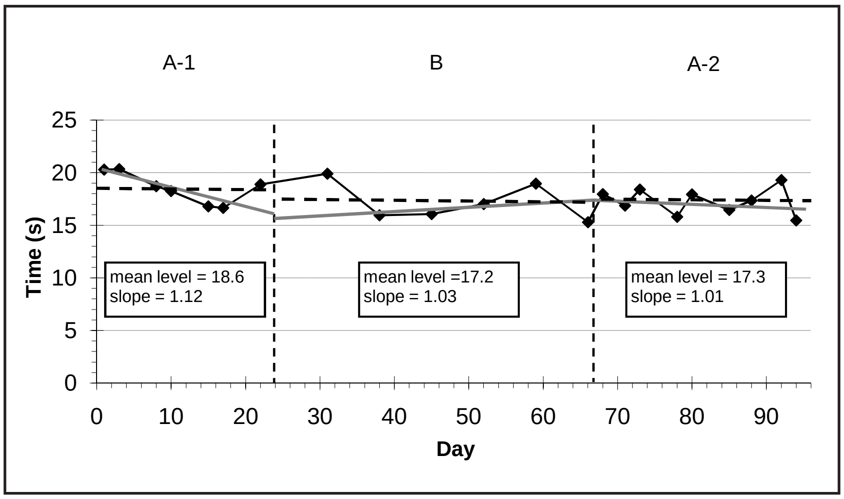

Figure 6. Scores for the timed 360° turn during each phase. Celeration lines are solid gray lines. The horizontal dashed lines show the mean level of the variable during each phase.

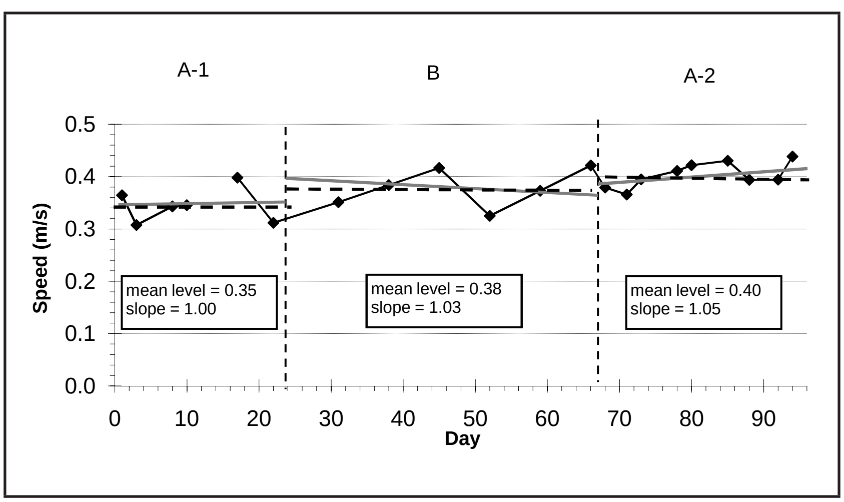

Figure 7. Self-selected gait speed, determined from the 10-m walk, during each phase. Celeration lines are solid gray lines. The horizontal dashed lines show the mean level of the variable during each phase.

session during the A-1 phase because of snow and ice covering the sidewalk used for the 10-m walk. In addition, we could not obtain data for hip abductor muscle strength on the paretic and nonparetic sides at one session during the A-2 phase because of a problem with the dynamometer.

Our first research aim addressed effects of the exercise program on hip abductor muscle strength and physical function. For hip abductor muscle strength, slight decreasing trends in peak force measurements for the paretic leg (Figure 2) and the nonparetic leg (Figure 3) were noted during baseline. These trends reversed to increasing trends for both lower extremities during the intervention phase, and these changes were significant according to the binomial test (p = 0.02). The level of the celeration line decreased from the end of phase B to the beginning of phase A-2 for both lower extremities. An increasing trend was again observed during the A-2 phase for the nonparetic but not for the paretic hip abductor muscles. Mean hip abductor peak force measurements improved from A-1 to B and from B to A-2 for both lower extremities.

With regard to physical performance, measures included single limb stance, timed 360° turn, the Step Test, and gait speed as determined from the 10-m walk at self-selected and fast speeds. During the baseline phase, the subject was essentially unable to perform single limb stance on either lower extremity without upper extremity support (Figures 4 and 5). Performance of this task improved bilaterally during the intervention phase, with the subject able to lift his foot off the floor consistently. Results of the binomial test indicated significant improvements in single limb stance bilaterally from A-1 to B phases (p = 0.02). An increasing trend also was noted during A-2 for single limb stance bilaterally.

The subject's times on the 360° turn decreased during the baseline phase (Figure 6). Although the binomial test was significant (p = 0.02), suggesting a worsening of performance from baseline to intervention, this result was not confirmed by visual analysis. The decreasing trend during baseline leveled off during the B and A-2 phases. The mean level of the variable improved slightly from A-1 to B and was unchanged from B to A-2.

The subject exhibited floor effects on the Step Test. He was unable to perform the Step Test with either lower extremity during the baseline phase. He came close to achieving a score of 1 for stepping with the paretic lower extremity at 3 test sessions during the intervention phase, as he was able to place his paretic foot on, but not off, the step. During the A-2 phase, the subject was able to complete one step (on and off) with the paretic lower extremity at 4 test sessions and one step with the nonparetic lower extremity at 2 test sessions.

Mean levels for gait speed were higher during intervention than baseline for both self-selected and fast gait (Figures 7 and 8). The slopes of the celeration lines during the B phase were quite low, however, indicating no effect of the intervention. Results of the binomial test indicated no significant changes in self-selected or fast gait speeds from A-1 to B phases. No negative effects of stopping the exercises were noted during the A-2 phase, with the binomial test results actually indicating positive change during A-2 as compared to B phases for both self-selected ($p = .004$) and fast ($p = .008$) gait speeds.

Our secondary aim was to determine whether the exercise program showed promise in affecting falls risk (as estimated by BBS score) and/or disability (as measured by the SIS). On the BBS, the subject scored 27 out of the maximum 56 points at the end of the baseline period. His score improved to 32 at the end of phase B, 34 at the end of phase A-2, and 36 at the 6-week follow-up. According to Stevenson,[75] a 6-point increase in BBS scores is necessary for one to be 90% confident that a clinically meaningful change has occurred in people who have had a stroke. Increases of 1 to 2 points were noted in the following items over the course of the study: transfer ability, standing unsupported with feet together, reaching forward with outstretched arm, picking up an object from the floor, turning to look behind over left and right shoulders, standing unsupported with one foot in front, and standing on one leg. The improvements in BBS scores were not large enough, however, to decrease the subject's estimated falls risk. With a score on the BBS of 36, he was at greater risk of falls as compared with individuals with BBS scores of 40 or higher.[74] The positive likelihood ratio for a score of 36 is 11.7, indicating that the subject is 11.7 times more likely to be a faller than a nonfaller.

On the SIS, the subject showed large gains following the intervention in scores on the strength and participation domains (Figure 9). According to Duncan and coworkers,[68] changes in SIS domain scores of approximately 10 to 15 points represent clinically meaningful change. Some of the improvement in strength domain scores was lost by the end of A-2, but the improvement in the participation domain was maintained throughout the study, with further improvement at the 6-week follow-up. The subject's stroke recovery rating (in response to the last question on the SIS, which states "On a scale of 0 to 100, with 0 representing no recovery and 100 representing full recovery, how much have you recovered from your stroke?") increased from 50 at the end of baseline to 75 at the end of phase B and 80 at the end of A-2. This rating was unchanged at follow-up.

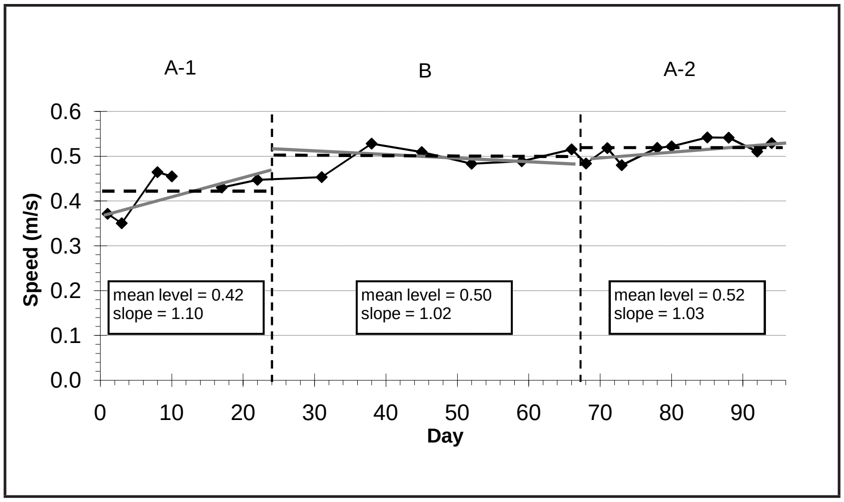

Figure 8. Fast gait speed, determined from the 10-m walk, during each phase. Celeration lines are solid gray lines. The horizontal dashed lines show the mean level of the variable during each phase.

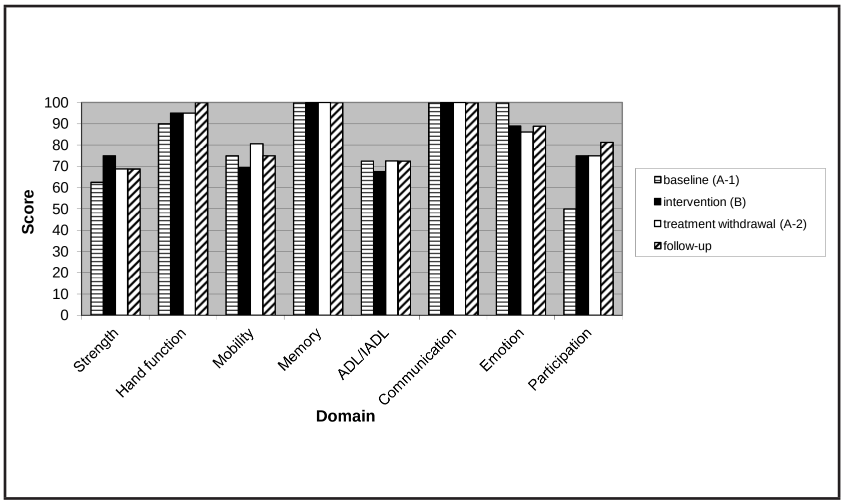

Figure 9. Stroke Impact Scale (SIS) domain scores during each phase and at 6-week follow-up.

DISCUSSION

Results of this study support the feasibility of a home-based exercise program targeting magnitude and rate of force development of the hip abductor muscles for persons with chronic stroke. The subject was able to perform the exercises, including lateral trainer exercises, safely. He showed improvements in several measures, including measures of impairment, physical performance, and disability/quality of life.

Increases in hip abductor muscle strength bilaterally, while relatively modest, may have contributed to improved lateral stability during performance of both static and dynamic activities. Hip abductors of the flexing limb are critical for moving from bipedal to unipedal stance, and those of the stance limb are critical for maintaining lateral stability once unipedal stance is attained. Although the gluteus medius is the muscle thought to contribute most to hip abduction peak force, contributions of other muscles to exercise and strength testing performance cannot be ruled out with the methods used in our study. Other researchers have reported that activation of the gluteus minimus,[76] hip adductors,[77] and the superior portion of the gluteus maximus,[78] as well as passive restraint by the iliotibial tract,[79] may contribute to frontal plane postural control. Improvements in lateral stability were evidenced by higher scores for single limb stance on the paretic and nonparetic sides and by gains in BBS scores. Gains were noted on BBS items both similar to and quite different from activities performed as part of the intervention. These improvements were lasting, persisting throughout the A-2 phase and at follow-up.

Little change was noted, however, in scores on the timed 360° turn or in gait speed. Although mean scores on these measures improved slightly over the course of the study, these improvements cannot be attributed to the intervention. Most of the change occurred during the baseline phase for the timed 360° turn and for fast gait speed. Trends during the intervention phase actually suggested slight worsening of performance. We believe that these trends may have resulted from mild overtraining or fatigue effects.[80] The subject's enthusiasm for the exercises and his desire to progress the program while at the same time continuing his daily walking routine may have produced overtraining.

Mean levels of all measures improved from one phase to the next throughout the study, and the celeration lines indicated positive trends during the A-2 phase for all measures except hip abductor muscle strength on the paretic side. These findings may be explained by motor learning effects and/or incorporation of new abilities into performance of routine daily activities. Moritani and deVries[42] emphasized the importance of neural factors in producing adaptations to exercise training in older adults. With practice and repeated testing, the subject may have not only increased maximal muscle activation level in the lower extremities, but also learned to some extent how to use that muscle activation for better postural control. These gains were not lost during treatment withdrawal. In our opinion, larger gains might have been achieved if the subject had not continued to rely heavily on upper extremity strength and use of the rolling walker.

The exercise program appeared to have positive effects on the subject's quality of life, as indicated by improvements in SIS strength and participation domain scores and by the 50% improvement (from 50 to 75) in the subject's stroke recovery rating. He remained at risk for falls, however, and his gait speed was still quite slow. Based on his self-selected gait speed of approximately 0.4 m/s, he would be classified as a "most-limited community walker."[81] His ability to enter and exit his apartment and manage curbs without assistance is consistent with this classification, as is his need for assistance (wheelchair use) in shopping centers. His fast gait speed was well below the 0.71 m/s required for crossing an intersection with the slowest walk signal.[82]

This study had several limitations. Although the researchers took steps to help insure consistency in testing and to avoid experimenter bias, inter-rater reliability was not formally evaluated and the possibility of bias still existed. Limitations of the testing environment (the subject's apartment), such as the space available and the nature of the walking surface, also may have affected the results. Because the overall duration of the study was limited by the subject's and the researchers' schedules, stability of baseline data could not be obtained for some measures, and this complicated the interpretation of the results for those measures. The 6-week intervention program may not have allowed adequate time for more marked improvements in strength and physical performance to occur. In addition, improvements in physical performance and disability may not have been related to changes in hip abductor muscle strength. The subject's exercise program undoubtedly involved activation and possible strengthening of muscle groups other than the hip abductors.

Despite these limitations, the positive results obtained in this study support the need for further research examining the effects of exercise interventions targeting muscle groups that are critical for lateral stability. Randomized controlled trials with adequate numbers of subjects will provide the strongest evidence regarding the appropriateness and relative benefits of these interventions for various subgroups of persons with chronic stroke.

CONCLUSION

A home-based exercise program targeting hip abductor muscle strengthening, including lateral trainer exercises, can be performed safely by a subject 3 years poststroke. The subject demonstrated improvements in measures of impairment, physical performance, and disability. Although many of these improvements were small, results of this study provide evidence to support further investigation of this type of exercise intervention for persons with chronic stroke.

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