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Progressive Adaptive Physical Activity in Stroke Improves Balance, Gait, and Fitness: Preliminary Results

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Abstract

Purpose—We conducted a noncontrolled pilot intervention study in stroke survivors to examine the efficacy of low-intensity adaptive physical activity to increase balance, improve walking function, and increase cardiovascular fitness and to determine whether improvements were carried over into activity profiles in home and community.

Method—Adaptive physical activity sessions were conducted 3 times/week for 6 months. The main outcomes were Berg Balance Scale, Dynamic Gait Index, 6-Minute Walk Test, cardiovascular fitness (VO_2 peak), Falls Efficacy Scale, and 5-day Step Activity Monitoring.

Results—Seven men and women with chronic ischemic stroke completed the 6-month intervention. The mean Berg Balance baseline score increased from 33.9 ± 8.5 to 46 ± 6.7 at 6 months (mean $\pm$ SD; $p = .006$). Dynamic Gait Index increased from 13.7 ± 3.0 to 19.0 ± 3.5 ($p = .01$). Six-minute walk distance increased from 840 ± 110 feet to 935 ± 101 feet ($p = 0.02$). VO_2 peak increased from 15.3 ± 4.1 mL/kg/min to 17.5 ± 4.7 mL/kg/min ($p = .03$). There were no significant changes in falls efficacy or free-living ambulatory activity.

Conclusion—A structured adaptive physical activity produces improvements in balance, gait, fitness, and ambulatory performance but not in falls efficacy or free-living daily step activity. Randomized studies are needed to determine the cardiovascular health and functional benefits of

structured group physical activity programs and to develop behavioral interventions that promote increased free-living physical activity patterns.

Keywords

balance; free-living activity; gait; progressive physical activity; stroke

Stroke is the leading cause of adult disability in the United States. Every year, more than 795,000 Americans experience strokes, two thirds of whom go on to live with residual neurological deficits.¹ These deficits disrupt gait and balance, increase fall risk, and promote social isolation and sedentary behaviors. Physical inactivity after stroke contributes to cardiovascular deconditioning, muscle weakness and gait impairments, and associated declines in physical and social function. Following completion of structured rehabilitation, patients are at risk of developing behavioral patterns of inactivity that lead to a declining spiral of deconditioning, fatigue, functional loss, and cardiometabolic risk.² There is a need to develop poststroke rehabilitation strategies that will promote and sustain ambulatory activity in home and community.

Task-oriented models of poststroke aerobic exercise and motor learning increase fitness, improve insulin-glucose metabolism, and increase walking function associated with neuroplastic and skeletal muscle mechanisms, even years after stroke.^{3–6} However, the effects of these exercise models are negligible on balance, falls efficacy, fatigue, or ambulatory activity in the community, all important determinants and indicators of improved daily function and quality of life for stroke survivors. There is a need for effective, low-cost models of poststroke exercise that improve these stroke outcomes and can be readily translated into community settings.

Based on initial pilot studies of an adaptive physical activity intervention in Italy,^{7,8} we developed and tested a progressive version of the adaptive physical activity model that (a) increased the dynamic balance challenge, (b) enhanced the structure of activity progression, and (c) incorporated high-intensity stepping to optimize fitness gain. The rehabilitation program included both gymnasium and home exercise components. The exercises focused on practicing gait and balance by performing commonly occurring movements of daily life, such as overground walking, weight shifting, reaching, standing and sitting, and navigating obstacles. We hypothesized that a progressive adaptive physical activity program would improve fitness, gait, and balance, making it physically possible to walk more, and that the exercise homework would encourage increased activity in everyday life. The specific aims of this study were (a) to determine whether adaptive physical activity improves cardiovascular fitness, (b) to quantify the effects of adaptive physical activity on gait and balance and free-living ambulatory activity, and (c) to determine whether adaptive physical activity affects self-reported outcomes related to self-efficacy.

Method

Ten community-dwelling men and women 61–79 (mean 71) years of age, with mild-to-moderate hemiparetic gait deficits after ischemic strokes, volunteered for the study in response to advertisements and presentations at community stroke clubs. Mild-to-moderate hemiparetic gait was defined as observable asymmetry of gait that included reduced stance time or reduced stance time and increased swing time in the affected limb. Participants had preserved capacity for ambulation, most with assistive devices (cane, walker) and/or standby assistance, and could ambulate for a sufficient duration to allow treadmill testing with handrail support at a speed of at least 0.2 miles per hour (.09 m/s).

Exclusion criteria were designed to ensure patient safety and to control for chronic comorbid conditions that would affect responses and participation independent of stroke, such as congestive heart failure (New York Heart Association class >II), unstable angina, peripheral arterial occlusive disease (Fontaine class >II), global or major receptive aphasia, screening criteria consistent with dementia (Mini-Mental Status Exam <23), current untreated major depression (Center for Epidemiological Studies-Depression scale [CES-D] >16), or other major medical, neurological, orthopedic, or chronic pain conditions that would preclude safe participation in study physical activities.

The protocol was reviewed and approved by the University of Maryland Institutional Review Board and the Baltimore Veterans Affairs Research and Development Committee, and subjects provided informed consent prior to participation. Baseline evaluations for eligibility entailed a comprehensive history, physical, and neurological exam by an experienced neurologist or nurse practitioner, cardiovascular assessment, psychosocial questionnaires, and functional testing.

Testing Procedures and Measurements

We report on the baseline, 3-month, and 6-month results that include the Berg Balance Scale (BBS), Dynamic Gait Index (DGI), 6-Minute Walk Test (6MW), VO₂ peak, Falls Efficacy Scale, and Step Activity Monitoring (SAM).

Berg Balance Scale (BBS)

The BBS measures the patient's ability to maintain balance, either statically or while performing various functional movements.⁷ A global score is calculated out of 56 possible points. Scores of 0 to 20 represent balance impairment, 21 to 40 represent acceptable balance, and 41 to 56 represent good balance. We conducted the BBS on the same day as the DGI, separated by a rest break.

Dynamic Gait Index (DGI)

The DGI was developed for use in community-living older people and also in chronic stroke.⁸ The eight items on the DGI require people to modify their gait while ambulating, such as varying speed, turning the head, walking over or around objects, and climbing stairs. Higher scores indicate better performance, with scores of less than 20 indicative of fall risk. The DGI accurately captures change in balance-related rehabilitation programs.⁹

6-Minute Walk Test (6MW)

The 6MW measures the maximum distance that an individual can walk in 6 minutes; it is commonly used to assess function in patients with chronic disease. The 6MW is useful because of its ease of administration and similarity to normal daily activities. We had participants walk a 100-ft course in an open hallway, following the standard administration procedure outlined by Enright.¹⁰

VO₂ peak

Participants underwent a physician-supervised screening treadmill test to ascertain safety and tolerance of graded exercise testing and to facilitate acclimatization.¹¹ On a subsequent visit, peak exercise capacity (VO₂ peak) was measured by open circuit spirometry during a constant velocity, progressively graded treadmill test to the point of volitional fatigue as reported previously.¹¹

Falls Efficacy Scale

Self-reported confidence in performing everyday activities without falling was measured with the self-report Falls Efficacy Scale¹² at baseline and after 6 months of training.

Step Activity Monitors (SAM)

SAM is used to assess ambulatory activity during day-to-day life. It is a small, waterproof, self-contained device that is worn on the ankle and records the rate and number of strides taken every minute. The SAM provides no immediate feedback to the subject, so it does not encourage performance behavior. When calibrated to individuals, step detection accuracy exceeds 98% both for unimpaired gait and for hemiparetic gait.^{13,14} Participants wore the SAM for periods of 5 days, including exercise sessions and weekends, and data were averaged and reported for a 24-hour period.

Intervention

The exercise intervention consisted of group sessions in the Senior Exercise Rehabilitation Center at the Baltimore Veterans Affairs Medical Center. Participants exercised 3 days a week for 1 hour and did homework exercises on alternate days over a period of 6 months. A key feature of adaptive physical activity is the presence of social reinforcement: Participants are enrolled in cohorts and perform the exercise activities together in a group. The activities were progressed in intensity, duration, repetitions, and complexity through the 6-month program.

With rhythmic music playing, participants began with a timed walking warm-up session around the indoor track. Then they moved to wall-mounted ballet-style bars and performed a series of balance exercises, including weight-shifting, leg lifts, foot placement routines, and partial squats. They marched while holding the bar for a gradually progressing number of minutes, concentrating on lifting knees high and alternating legs as symmetrically as possible. Participants then sat in chairs and completed a series of upper body exercises designed to build trunk stability and posture correction. They performed sit-to-stand exercises. The sessions ended with a timed walk on an obstacle course that included a serpentine walk, stepping in and out of hoops on the floor, and negotiating a wide step. During the obstacle walk, participants were encouraged to watch themselves in a full-length mirror and to use the visual feedback to help with adjusting posture while walking. Progression of the adaptive physical activity program is summarized in Table 1.

In addition, each participant was given an individual home exercise program that paralleled the activities in the gym. The homework log was checked at each session, and obstacles or challenges were discussed in the group. Knowledge of participants' home environments and mobility goals was incorporated into the class activities. The corresponding home exercise component encourages participants to practice activities learned in the class in their home environments and to progress them along with the gym-based program.

Over 6 months, walking increased from 6 minutes to 12 minutes per session. Marching began at 2 minutes and progressed to 6 minutes of continuous stepping. The distance of the obstacle course was extended to include the entire track, and the total number of minutes was doubled. Balance exercises began with 5 repetitions each and progressed to two sets of 10 repetitions for all exercises. Complexity was developed by adding elements to the obstacle course, such as additional hoops and steps, making tighter angles in the serpentine walk, and using the mirror for simultaneous visual feedback. The home program was likewise progressed to remain parallel with the gym exercise progression.

Data analysis

Data were analyzed using SPSS version 10.0 (SPSS, Inc., Chicago, IL). Descriptive statistics were generated using the descriptive and frequency subroutines for interval and ordinal data. Two-tailed *t* tests were used to analyze pre- and postintervention measures. Significance was set at $p < .05$. Data are reported as mean $\pm$ *SD*.

Results

The cohort included seven men and three women. Four participants were African American, and six were White. The average age of the sample was 71 years, ranging from 61 to 79 years. All had chronic hemiparetic stroke deficits, with the average time since stroke at 7.5 years (range 4–22 years). Four participants had right-sided stroke. There were three drop-outs during the study, all due to medical reasons including cardiac issues not cleared for participation in exercise, failure to thrive due to an unanticipated non-stroke-related condition, and back pain precluding exercise.

Functional measures

All subjects improved in BBS scores from an average baseline score of 33.9 ± 8.5 to 46.0 ± 6.7 ($p = .005$) after 6 months of training. This represented a difference of over 12 points. The DGI score increased from 13.7 ± 3.0 at baseline to 16.3 ± 4.3 at 3 months and 19 ± 3.5 points at 6 months ($p = .006$). 6MW improved by 11% from a mean baseline of 840 ± 110 ft to 935 ± 101 ft at 6 months ($p = .03$).

Cardiovascular measures

VO₂ peak values were 15.3 ± 4.1 mL/kg/min at baseline. This improved only slightly at 3 months to a mean of 16.2 ± 4.1 mL/kg/min and a 6.5% change, but by 6 months the VO₂ peak had increased 15% to 17.5 ± 4.6 mL/kg/min ($p = .03$).

Activity measures

SAM showed a mean of 2608 ± 1563 steps per day at baseline and 3003 ± 748 at 6 months ($p = .62$), indicating no measurable change in daily step activity pre and post training. Falls Efficacy Scale scores were 15.5 at baseline and did not change at 6 months (15.9). Results are summarized in Table 2.

Discussion

The findings in this noncontrolled pilot study show that structured physical activity classes produce meaningful functional improvements in balance, gait, fitness, and ambulatory performance in the lab but no improvements in falls efficacy or free-living daily step activity. We report the most significant improvement in BBS, DGI, and 6MW distances. Individuals with stroke often report that their activity levels are strongly influenced by balance difficulties and fear of falling. In a previous study, we reported that the BBS predicted 30% of the variance in ambulatory activity.² The gains realized in just 3 months of adaptive physical activity training brought the participants from “adequate” to “good” balance. By 6 months the gains were even greater, more than 12 points, to an average of 46 points. Increases in BBS of this magnitude are associated with reduced fall risk and lesser assistive device requirements.¹⁵ These findings demonstrate that by using a simple adaptive activity model that incorporates progressive overground walking, weight shifting, and reaching activities, balance can be improved significantly even years after a stroke, with implications for increased safety and function.

The intervention includes progressive practice of overground walking, foot placement, pattern stepping, and stepping up and down and over objects. These are conditions meant to mimic situations in daily life that challenge mobility, such as negotiating architectural barriers and environmental features in home and community. Dynamic gait improved from a mean of 13.7 to 19.0 after 6 months of training, a score associated with reduced fall risk.¹⁶

The profound cardiovascular deconditioning encountered in the sample offers another potential influence on ambulatory activity. In every case, VO_2 peak was below age-matched levels needed for functional aerobic capacity for activities of daily living. It was not until the 6-month point that a significant change of 15% was noted; this probably relates to the progression of walking and marching during the exercise sessions, as well as improved efficiency of gait and stride length, which reached their peak during the second half of the exercise program. Such gains in VO_2 peak compare favorably with the results of other exercise models. For example, cycle training in individuals with stroke has produced VO_2 peak gains of 13%.¹⁷ Treadmill exercise typically yields 10%–17% gains in similarly disabled subjects with stroke.^{4,18} Combined aerobic and resistance training programs have produced gains in VO_2 peak around 8%.¹⁹ However, the adaptive physical activity intervention takes a longer period of time to produce the fitness gains compared to more intense interventions.

Individuals with chronic stroke face many challenges to attaining and sustaining activity levels associated with health and well-being. Previous studies from our lab show that even stroke survivors who volunteered for an exercise program have daily step activity well below the established sedentary levels of 3,000 to 5,000 steps per day in age-matched healthy adults.² All of the participants in this study have very low step activity that did not change substantially with the activity intervention. They report no change in their self-assessment of falls efficacy. Even though the participants have mild-to-moderate gait deficits and retained the ability to walk independently or with assistive devices, they nonetheless walk very little in their daily lives; our results show this did not change with the intervention.

The possibility emerges that step counts alone may not show the effects of adaptive physical activity on gait efficiency. For example, increases in symmetry and stride length, as has been reported to accompany task-oriented treadmill training,²⁰ would allow an individual to cover more ground by taking a similar number of total steps. Six-minute walk measurements show that substantially more distance is covered. This indicates that it will be valuable to measure gait parameters to characterize changes in walking function as well as step activity, accelerometry, and other indices of movement.

Even though adaptive physical activity can build the capacity to increase activity by improving balance, gait patterns, and walking distance and endurance, changing exercise behaviors in everyday life remains an unsolved challenge. The question remains: how do we help stroke survivors to effectively build health- and function-promoting exercise behaviors into their everyday lives? The results from this pilot study suggest that the adaptive physical activity model has specificity to improve distinct physical and functional domains of gait, balance, and walking distance, and they define some future areas for targeted intervention.

The social reinforcement that occurs in the group exercise model warrants further examination. Participants frequently offer encouragement and helpful suggestions to each other during the exercise sessions. In discussions, they relay the feeling that they belong to and identify with the group and attend the sessions consistently because they enjoy being together. Attendance across the entire 6-month intervention was 73%. Social networks may subtly or directly encourage physical activity by promoting a sense of belonging, purpose, and self-worth, promoting mental health that may be reflected in low self-perceived fatigue and positive activity levels.²¹ One key aspect of adaptive physical activity is the social milieu and the

opportunity to integrate and reinforce behavioral change strategies to improve daily mobility function in stroke.

Our results should be interpreted with caution due to the very small sample size and lack of a randomized controlled design. The participants were volunteers, who may be more healthy, functional, and highly motivated to exercise than the general stroke population. However, the clinical implications of the improvements in balance, gait, and fitness realized in this small study have far-reaching applications and show that it is possible to induce clinically meaningful improvements long after stroke, using a progressive adaptive physical activity paradigm.

Conclusion

Adaptive physical activity is a model of exercise rehabilitation that produces meaningful functional improvements in gait, balance, fitness, and ambulatory performance in the lab but not in free-living daily activity or falls efficacy. This study demonstrates the efficacy of a model of low-intensity physical activity on important domains of stroke recovery. Further studies are needed to develop strategies to enhance the translation of functional improvements gained in the lab into community-based activity patterns in the everyday lives of individuals with stroke.

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Table 1**Progression of the adaptive physical activity program**

Exercises	Progression
Overground walking warm-up around indoor track	6–8–10–12 minutes
Weight shifts at bar	5–8–10–20 repeats each limb
Step forward	5–8–10–20 repeats each limb
Step to side	5–8–10–20 repeats each limb
Step to back	5–8–10–20 repeats each limb
Partial squats	5–8–10–20 repeats
Leg lifts to back	5–8–10–20 repeats each limb
Leg lifts to side	5–8–10–20 repeats each limb
Leg lifts to front	5–8–10–20 repeats each limb
Toe touch to box	5–8–10–20 repeats each limb
Marching in place with knees high	2–3–4–5–6 minutes continuously
Sitting in regular chair: Arm raises over head	5–8–10–20 repeats
Sitting in regular chair: Trunk twists	5–8–10–20 repeats each direction
Sitting in regular chair: Reaching toward floor on either side	5–8–10–20 repeats each direction, added center reaching component in last month
Sitting in regular chair: Stand up/sit down, not using arms if possible	5–8–10–20 repeats
Obstacle course walking	6–7–8–10–12 minutes, added hoops in zigzag formation, steps, and increasingly complex rope serpentine course. Visual feedback with full-length mirror.

Table 2Baseline, 3-month, and 6-month outcomes (mean $\pm$ SD)

Measure	Baseline	3 Months	6 months	Change	p
Berg Balance Scale	33.9 $\pm$ 8.5	44.6 $\pm$ 6.7*	46.0 $\pm$ 6.7*	+ 12 points	.005*
Dynamic Gait Index	13.7 $\pm$ 3.0	16.3 $\pm$ 4.3	19 $\pm$ 3.5*	+ 5 points	.006*
6-minute walk	840 $\pm$ 110 feet	895 $\pm$ 275 feet	935 $\pm$ 101 feet*	11% gain	.02*
VO ₂ peak	15.3 $\pm$ 4.1 mL/kg/min	16.2 $\pm$ 4.2 mL/kg/min	17.5 $\pm$ 4.6* mL/kg/min	15% gain	.03*
Falls efficacy	15.5	n/a	15.9	2% gain	.63
Step activity	2608 $\pm$ 1563	2671 $\pm$ 1514	3003 $\pm$ 748	15% gain	.62

*
p < .05.