JRRD
Journal of Rehabilitation Research & Development
Vol. 36 No. 3, July 1999

Gait characteristics of individuals with multiple sclerosis before and after a 6-month aerobic training program

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Abstract--Individuals who have multiple sclerosis (MS) typically experience problems with physical activities such as walking, resulting from the combined effects of skeletal muscle weakness, sensory disturbances, spasticity, gait ataxia, and reduction in aerobic capacity. The aim of this study was to determine whether a 6-mo exercise program designed for aerobic conditioning might also affect gait abnormalities in individuals with MS. Subjects included 18 individuals with MS who presented a range of disability. Passive range of motion (PROM) in the lower limbs was measured and gait analyzed before and after exercise conditioning. Three-dimensional kinematics, ground reaction forces (GRF), and electromyographic information were acquired as subjects walked at self-selected velocities. Hip PROM increased following conditioning. Mean walking velocity, cadence, and posterior shear GRF (push-off force) decreased. During walking, maximum ankle dorsiflexion decreased and ankle plantarflexion increased. Total knee flexion/extension range during the walking cycle decreased slightly as did maximum hip extension. Results suggest this 6-mo training program had minimal effect on gait abnormalities.

Key words: *cardiorespiratory fitness, gait, neurological, rehabilitation.*

INTRODUCTION

Multiple sclerosis (MS) is a disease with a progressive clinical course most often resulting in severe disability. Its symptoms include muscle weakness, sensory disturbances, spasticity, and gait ataxia (1-4). People with MS typically demonstrate a decline in physical activity, particularly in those activities requiring walking. The decline in walking ability may be the result of a reduction in aerobic capacity and the presence of one or more of the aforementioned symptoms resulting from progression of the disease process. Recently, Petajan, et al. (5) reported the results of a 15-week aerobic exercise program in subjects with MS. Aerobic conditioning resulted in a 22 percent increase in maximal oxygen consumption (VO_{2max}), a 48 percent increment in maximal power output (PO_{max}), and a significant improvement in body composition and serum triglyceride levels. These data support earlier research from Ponichtera-Mulcare and associates (6,7) which found improved VO_{2max} and PO_{max} following 6 mo of supervised training using stationary cycling. However, neither of these studies addressed the relationship between aerobic conditioning and functional improvement in ambulation.

Gehlsen, et al. (8) compared gait characteristics of nine patients with MS before and after an aquatic exercise program. No significant changes in subject gait were found; however, the intensity of the exercise program was not monitored closely, disability level in the sample was very low, and the type of exercise performed varied among subjects. These confounding elements make it difficult to interpret the relationship between exercise training and gait changes. In addition, the training program duration was 10 weeks, which may have been too short to result in improvements in gait characteristics. In pilot work from this laboratory (9), gait characteristics measured after 3 mo of training were not significantly different from pre-training values. However, changes in these characteristics reached statistical significance after an additional 3 mo of training. The results of such research may improve the clinician's understanding of therapeutic exercise intervention for people who have MS. However, information from subjects with MS presenting a broad range of disability is needed before aerobic exercise intervention can be assumed to be effective. The purpose of this study was to examine the influence of an aerobic exercise program on lower extremity kinematics and kinetics during gait in patients with MS who demonstrate a range of disability.

METHODS

Subjects

Eighteen patients (14 female, 4 male) with MS of differing levels of disability participated in this study. After informed consent, subjects were examined by a neurologist. The Kurtzke Expanded Disability Status Scale (EDSS) was used to quantify the severity of the disease for each subject (10). EDSS scores were determined through a neurological examination, with scores ranging from 0 (normal neurological examination) to 10 (death from MS). Scores greater than 7 indicate restriction to a wheelchair. The range of scores for these subjects was 1.0 to 6.5. Subjects with a score greater than 4 (n=8) utilized a cane or walker while walking.

Aerobic Conditioning Program

The aerobic exercise conditioning program was performed by each subject in a clinical research laboratory under supervision (6). The program consisted of a cycle ergometry protocol in which the subjects exercised three times a week for 30 min while maintaining a heart rate (HR) of 65 to 70 percent of their age-predicted maximum (11). The subjects exercised using combined arm/leg cycling at submaximal power output levels and either an upright or recumbent ergometer depending on their ability level. HR was monitored continuously during training, using a telemetry chest band and watch system. As improvement occurred, power output intensity was adjusted to elicit a submaximal exercise response comparable to 55 percent of each individual's maximal aerobic capacity. The exercise program lasted 24 weeks with no lapse in attendance of greater than 2 weeks (i.e., 6 consecutive visits) allowed for personal or non-MS related illness to ensure compliance of all participants.

Gait Analysis

Gait analysis instrumentation included a video-based three-dimensional (3-D) motion measurement system (Peak Performance Technologies, Englewood, CO) incorporating three fixed-position cameras (Panasonic 5100, Matsushita Corp., Tokyo, Japan) for collection and analysis of walking kinematics. Fixed camera positions were 0°, +45°, and -45° from the X-axis and tilted down 30° from the horizontal (**Figure 1**). Ground reaction forces (GRF) were collected at a 1000 Hz sample rate, using a Kistler force plate (Kistler Instrument Corp., Amherst, NY). The force plate was built into a 6.5 m walkway covered with vinyl floor tiles.

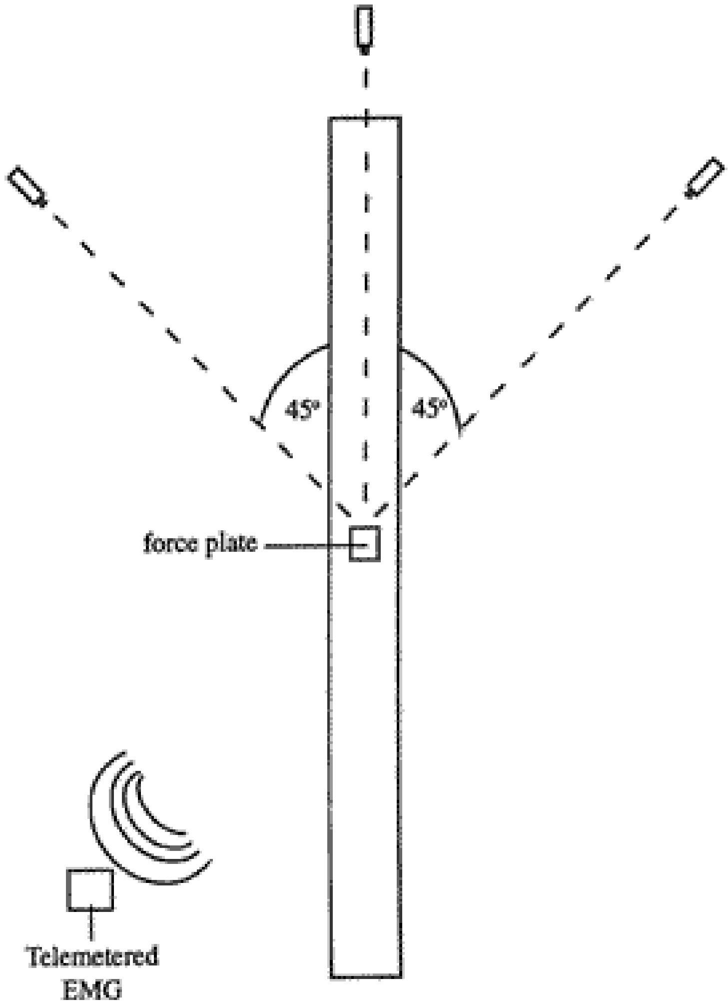

Figure 1.
Schematic of the data collection experimental set-up showing the camera and force plate placement. Fixed camera positions were 0°, +45°, and -45° from the X-axis and tilted down 30° from the horizontal.

Gait analysis was conducted prior to (pre) and following (post) the 6-mo exercise conditioning program. Passive range of motion (PROM) measurements, using manual goniometers and standard techniques (12), were taken prior to the gait analysis. Retro-reflective markers (3-M Corp., Baltimore, MD) were placed bilaterally on five sagittal bony landmarks at the fifth metatarsal head, lateral malleolus, acromion process, greater trochanter, and lateral femoral epicondyle for each individual. Subjects were instructed to walk at their normal walking velocities on the 6.5 m walkway while 3-D kinematic and GRF data were collected. A minimum of six walking trials (three left and three right contacts) were obtained in which a single foot contact occurred on the force plate built into the walkway. All participants performed walking tests in their own shoes and without assistive devices or orthoses.

Test of Maximal Aerobic Power (VO_{2max})

To assess aerobic fitness level, a test of maximal aerobic power was administered pre- and post- the 6-mo exercise conditioning program. A leg cycling ergometer, adapted to allow subjects to sit in a semi-recumbant position, was used for the test. A discontinuous, incremental intensity, protocol to maximum which has been previously described was performed (6). Following a 5-min rest period, subjects performed four 5-min workrates, with each exercise bout separated by a 5-min rest. Upon completion of the submaximal levels, a final stage was performed in which exercise intensity was increased each minute until the subject reached volitional fatigue, or a plateau or decrease in oxygen uptake with increased workrate. A MedGraphics 2001 Metabolic Analyzer (Medical Graphics Corp., St. Paul, MN) was used to measure metabolic and ventilatory data using breath-by-breath samples averaged every 15 s. HR was monitored continuously, and arterial blood pressure was measured using a manual sphygmomanometer between the third and fourth minute of each submaximal workrate, and immediately after test cessation.

Data Analysis

Kinematic data were collected at 60 Hz, digitized and smoothed using a 2nd order Butterworth filter with a cut-off frequency of 3-5 Hz. Kinematic and kinetic data were averaged over three walking cycles and three walking trials and then normalized to percent of average contact and percent stride. EDSS scores before and after training were compared using a paired t-test. Statistical analysis for all PROM, kinematic, and kinetic variables consisted of repeated measures ANOVAs with main effects for time (pre:post) and leg (right:left). The relationship between EDSS scores and training changes was assessed through correlation. ANOVA was used to examine VO_{2max} data. The significance level for all statistical tests was 0.05.

RESULTS

Subject characteristics are summarized in **Table 1.** Overall, EDSS scores did not change significantly during training. However, six participants demonstrated neurologic decline as determined by a post-training neurologic examination. Due to the gross nature of the EDSS score, a patient may experience a decline within one of the eight subcategories of the EDSS without affecting (i.e., increasing) the actual EDSS score. The change in aerobic fitness based on VO_{2max} has been previously reported for these subjects(6). They demonstrated a mean VO_{2max} gain of 15 percent during the 24-week training period ($p<0.05$).

Table 1.

Subject characteristics.

Gender	14F, 4M
Age	43.2 ± 10.8 yr
Height	167 ± 8.5 cm
Weight	697.3 ± 83.4 N
	71.2 ± 8.5 kg
Kurtzke EDSS	Pre-training 3.6 ± 2.1
	Post-training 3.8 ± 2.2

P value <0.163.

Several kinematic changes in walking were found following the 6-mo training period. Mean velocity and cadence significantly decreased from 0.79±0.29 m/s to 0.72±0.38 m/s and 0.8±0.1 steps/s to 0.7±0.2 steps/s, respectively. **Table 2** shows that maximum dorsiflexion angle decreased and maximum plantarflexion angle increased.

Table 2.

Mean (±SD) ankle angles (in degrees) during walking pre- and post-training.

	Pre-	**Post-**	**p value**
Ankle dorsiflex*	71.1 (5.3)	77.0 (8.1)	0.0007
Ankle plantarflexion*	101.0 (8.7)	108.9 (8.3)	0.0001
Ankle ROM	29.8 (7.1)	31.9 (8.8)	0.2043
Ankle angle at contact	89.2 (5.3)	97.0 (7.3)	0.0001
Ankle angle at toe-off	92.9 (9.1)	99.5 (10.7)	0.0037

*90°=neutral; significant changes (p<0.05).

Ankle angle at foot contact and toe-off was more plantarflexed after training. In general, the foot was carried in a more plantarflexed position during walking. As shown in **Table 3,** the total knee range of motion (ROM) in flexion/extension decreased following training. At contact, the knee was in slightly more valgus at the post-test.

Table 3.

Mean (±SD) knee angles (in degrees) during walking pre- and post-training.

	Pre-	**Post-**	**p value**
Knee flexion*	122.5 (9.3)	124.3 (11.0)	0.1781
Knee extension*	172.0 (6.4)	171.0 (6.1)	0.3389
Knee ROM	49.5 (10.2)	46.6 (11.3)	0.0239
Knee angle at contact	165.1 (8.0)	165.6 (8.0)	0.7366
Knee angle at toe off	142.4 (7.9)	143.4 (11.8)	0.6449

*180°=neutral; significant changes (p<0.05).

Table 4 shows that maximum hip extension angle was reduced and total hip flexion/extension range was reduced. This indicates that the hip was generally more flexed during walking. In the transverse plane, maximum hip adduction increased and abduction decreased. Also, the hip was in greater adduction at foot contact following training.

Table 4.
Mean (±SD) hip angles (in degrees) during walking pre- and post-training.

	Pre-	**Post-**	**p value**
Hip extension*	176.0 (6.8)	172.0 (6.5)	0.0207
Hip flexion	151.1 (8.6)	151.0 (8.7)	0.9498
Hip ROM	24.9 (6.0)	21.0 (4.5)	0.0029
Hip angle at contact	156.6 (8.3)	157.8 (9.3)	0.4312
Hip angle at toe off	169.6 (6.9)	166.4 (7.3)	0.0521
Hip adduction	189.3 (6.8)	196.7 (4.7)	0.0000
Hip abduction	172.2 (6.7)	184.2 (4.5)	0.0000
Hip ROM	16.5 (6.8)	13.0 (6.1)	0.0712
Hip angle at contact	180.5 (6.0)	189.9 (7.7)	0.0000
Hip angle at toe off	182.1 (8.0)	187.3 (10.7)	0.0718

*180°=neutral; significant changes ($p<0.05$).

At the post-test, posterior (backward shear) ground reaction forces evident at push-off in gait were significantly reduced by 19 percent. **Table 5** summarizes significant PROM changes with training. Hip abduction, adduction, external rotation, and hip flexion with the knee extended increased for both legs. However, the Thomas test angle also increased, indicating an increase in hip flexor tightness.

Table 5.
Significantly different range of passive motion means (in degrees) pre- and post-training.

	Pre-	**Post-**	**p value**
Hip flexion (knee extended)	93.8 (11.4)	100.3 (7.0)	0.0348
Hip flexion (knee flexed)	128.8 (9.1)	126.0 (10.6)	0.1549
Hip extension	16.1 (3.8)	14.0 (2.5)	0.0928
Hip abduction	32.6 (9.2)	40.0 (10.8)	0.0006
Hip adduction	24.6 (9.7)	37.0 (13.0)	0.0010
Hip external rotation	31.0 (5.6)	40.6 (6.9)	0.0001
Hip internal rotation	34.3 (7.9)	37.8 (7.2)	0.1099
Knee flexion	139.4 (6.4)	140.6 (4.7)	0.1251
Ankle plantarflexion	48.8 (6.0)	47.6 (3.6)	0.5030
Ankle dorsiflexion	10.2 (3.3)	11.5 (3.8)	0.1555

Subtalar inversion	11.0 (2.3)	11.7 (2.6)	0.2636
Subtalar eversion	8.2 (3.2)	9.3 (1.9)	0.2272

Significant changes (p<0.05).

EDSS scores were significantly correlated with change in velocity (r=-0.613, p=0.012) and cadence (r=-0.572, p=0.021) such that subjects with higher EDSS scores, who had poorer function, walked slower at the post-test. EDSS scores were also significantly correlated with the decrease in posterior ground reaction force or push-off force (r=0.613, p=0.045).

DISCUSSION

Analysis of PROM revealed several trends at the hip joint. The increase in hip abduction/adduction and internal/external rotation indicates that specific ROM was favorably influenced by the exercise program. Because the exercise regimen required cycling, the sitting position may have had a negative effect on hip extension mobility, as indicated by the increase in hip flexor tightness.

Temporal results found in the present study indicate a decreased mean cadence and velocity following exercise training. While a decline in velocity is undesirable, it is unlikely that this represents a negative training effect. Hallmarks of MS are neurologic fluctuation and progression of the disease process, which lead to functional decline. In this study, high EDSS scores, indicating poorer function, were found to correlate significantly with decline in cadence and velocity. In other words, people with more severe symptoms of MS appeared to deteriorate functionally over the 6-mo training period, as reflected by decreased velocity. A third of the subjects in this study were known to decline neurologically during the 6 mo of training, based on neurologic examination or change in EDSS scores. All but one of these subjects demonstrated decreased walking velocity at the post-test. In addition, six other subjects demonstrated a similar slowing of velocity, which may be an early indicator of neurologic decline not reflected by the neurologic examination or EDSS rating. Compared to gait velocities reported for able-bodied adults (13-16), the mean cadence and velocity values found in this MS group were low both pre- and post-training. These findings are consistent with those of other reports specific to the MS population (1,4,8,17).

Several investigators have recorded kinematic data from able-bodied adults (13,14). Hip and knee excursions in this study were lower than those reported by Winter (18) for able-bodied adults walking at a slow pace. However, participants in this study walked considerably slower (45 steps/min) than Winter's subjects, whose slow pace was 85 steps/min. The low ROMs reported in this study are consistent with the slow walking velocity, demonstrating less excursion with slower speed. Changes in joint kinematics during walking, as found in this study, probably also reflect neurologic decline. The ankle position was more plantarflexed throughout the gait cycle. The knee ROM was smaller in flexion/extension, although this may be an effect of the reduction in walking velocity. Hip position tended to be more flexed. The reduction in passive hip extension range could explain the reduction in maximum hip extension angle and total hip flexion/extension range during gait. This appears to be a negative effect of the training, even though the hip angles during gait were already reduced compared to normal even before the training. The hip ROM would be expected to decrease in response to the reduction in walking velocity. The reduction found in push-off GRF could also be attributed to the decreased velocity.

The possible benefit of the exercise program for functional walking is difficult to ascertain, since exercise cannot alter the course of the disease. Because neurologic decline from MS occurred within the 6-mo time frame for several subjects, it is difficult to differentiate the effects of intervention from changes in status resulting from progression of the disease. Although the lack of a control group may be viewed as a limitation of this study, the use of a control group would not address the issue of intervention effects, because individuals within the control group would have individual patterns of disease progression that may or may not match those of the experimental group. This is a difficulty for any study of a group with progressive pathology.

CONCLUSION

Clinically significant improvements in gait were not observed in patients with MS after 6 months of aerobic exercise training although aerobic fitness improved as evidenced by improved VO_{2max} (6). Further work is needed to determine whether routine stretching would prevent the decrement in hip ROM that may result from cycling. Future investigation of the relationship between changes in balance and walking velocity and how changes in gait and balance influence energy utilization and walking efficiency would also be of benefit. Also, different modes of training may provide more functional benefits, without sacrificing the aerobic benefits achieved with cycling.

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