Department of Veterans Affairs

Journal of Rehabilitation Research and Development
Vol. 40, No. 6, November/December 2003
Pages 501–510

Improved upper-body endurance following a 12-week home exercise program for manual wheelchair users

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Abstract—This study determined if a 12-week monitored home exercise program would improve cardiorespiratory endurance in a heterogeneous group of manual wheelchair users, which incorporated subsets of individuals with and without upper-limb impairment. Twenty-seven subjects made up two groups of manual wheelchair users: 20 without upper-limb impairment and 7 with upper-limb impairment. Subjects completed wheelchair ergometer tests using a 1 min JUMP protocol that resulted in volitional exhaustion in 6 to12 min. Following a recovery period (time > 30 min), subjects completed subsequent constant work rate endurance tests to exhaustion at a power output corresponding to 60% of the maximum attained on the JUMP test. Subjects then underwent 12 weeks of simulated wheelchair rolling exercise using elastic straps positioned to mimic the motion of propulsion. JUMP and constant work rate tests were performed before training and after 6 and 12 weeks of exercise. Oxygen consumption (VO_2) increased from rest to peak exercise in both groups and was significantly ($p < 0.016$) higher at peak for subjects without upper-limb impairment than for those with upper-limb impairment. Heart rate (HR) responses between the groups were similar. No significant differences in peak VO_2, anaerobic threshold, or peak HR were observed at 6 or 12 weeks of the training program. Substantial improvement ($p < 0.001$) in maximum constant work rate tests time (10.37 ± 2.79 min) was noted at 6 and 12 weeks, with no significant difference between 6 and 12 weeks and no significant intergroup difference. Results of this study indicated that simulated propulsion exercise endurance was improved as a result of the home exercise program.

Key words: aerobic capacity, endurance, exercise conditioning, manual wheelchair users, upper-limb impairment, wheelchair propulsion.

INTRODUCTION

Manual wheelchair users have been determined to be at increased risk for cardiovascular [1,2], metabolic [2–4], and orthopedic overuse conditions [5,6]. Those who have acquired one of these conditions may experience further debilitation and decreased quality of life [7,8]. In general, increased physical fitness has been demonstrated to reduce the risk of acquiring systemic diseases, such as cardiovascular disease [9–17], type 2 diabetes mellitus [18–22], and certain neoplastic disorders [23–28]. Furthermore, as physical fitness increases, the likelihood that one would sustain an overuse injury to the joints may be diminished. Increased physical fitness has also been shown to enhance functional ability in people who use manual wheelchairs [29–31].

Abbreviations: AVOVA = analysis of variance, CI = confidence interval, EKG = electrocardiograph, HIV = Human Immunodeficiency Virus, HR = heart rate, ICC = intraclass correlation coefficient, PO = power output, SAS = Statistical Analysis System, SCI = spinal cord injury, SEM = standard error of measurement, VO_2 = oxygen consumption.

This material was based on work supported by the Department of Veterans Affairs merit review B2166RA, with Dr. Mary M. Rodgers as principal investigator.

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The ability to resist fatigue during prolonged activity, or cardiorespiratory endurance, has been identified as one characteristic of physical fitness [32]. Aerobic exercise conditioning has been demonstrated to improve cardiorespiratory endurance [32]. However, practical considerations associated with participating in aerobic exercise have often been deterrents for manual wheelchair users who may otherwise have engaged in these exercise regimens, particularly those who were not athletes and those who had upper-limb impairment. Inappropriate methods, lack of appropriate assistance, difficulty with access, and an uncomfortable environment may have resulted in nonadherence to exercise programs and increased the potential for injury.

As an alternative to the methods most commonly available for manual wheelchair users, this study investigated an in-home conditioning program. The method used elastic stretch bands fixed to a doorframe to provide resistance for simulated wheelchair propulsion exercise. This study determined if such a program would improve cardiorespiratory endurance in a heterogeneous group of manual wheelchair users, which incorporated subsets of individuals with and without upper-limb impairment.

METHODS

Subjects

Twenty-seven subjects (20 without upper-limb impairment and 7 with upper-limb impairment) completed the conditioning program. Of these subjects, 17 of the 27 had spinal cord injuries (SCIs). Of these 17, 2 had cervical lesions. Three of the subjects had spina bifida and two had cerebral palsy. One subject had arthrogryposis, one had brain abscess, and one had Buerger's disease with amputation below the right knee. One subject had lower-limb paralysis caused by the residual effects of polio, and three subjects were classified as having multitrauma paralysis. Subjects with altered or absent sensation, paresis, paralysis, or dyscoordination were classified with upper-limb impairment. Generally, conditions causing upper-limb impairment were cervical level SCI, cerebral palsy, or other brain injuries. All other subjects were classified "without upper-limb impairment." Descriptive information for those with and without upper-limb impairment is provided in **Table 1**. An individual qualified as a manual wheelchair user if she or he used a manual wheelchair for more than 50 percent of the time ambulating. No subject had cardiovascular, pulmonary, or metabolic disease that would limit her or his responsiveness to graded exercise testing or adaptability to aerobic exercise conditioning. No subject was on a medication regimen that limited participation in aerobic exercise testing or conditioning. All subjects were informed of the study procedures and expectations, her or his rights as a human subject, and risks and potential benefits of participation before beginning the study in accordance with the University Institutional Review Board's approval and general policies.

Apparatus

All exercise tests were done on a prototype wheelchair ergometer, described in detail elsewhere [33,34]. Briefly, the ergometer consisted of a seat assembly attached to wheels with hand rims, designed to produce wheel-movement that mimicked that of wheelchair propulsion when force was applied by the upper limbs. The seat width, back height, and leg position were adjusted to accommodate each subject's physical characteristics and to match, as closely as possible, each subject's wheelchair. The ergometer wheels were attached by a sprocket and chain system to a flywheel. The roll distance of this assembly (distance flywheel would traverse with one turn of the hand rims if not stationary) was 6.32 m. A nylon strap braking assembly that encircled the flywheel was used to apply resistance to propulsion. The strap was

Table 1.
Age, weight, gender distribution, height, and years of wheelchair use for manual wheelchair users without upper-limb impairment and with upper-limb impairment.

Users	Age (yr)	Height (cm)	Gender (M/F)	Weight (kg)	Wheelchair Use
All Subjects (n = 27)	41 ± 10	168.9 ± 13.8	20/6	73.8 ± 15	11.9 ± 08.5
No Upper-Limb Impairment (n = 20)	43 ± 10	169.9 ± 12.5	15/4	78.5 ± 13.8*	11.1 ± 8.3
Upper-Limb Impairment (n = 7)	36 ± 07	166.2 ± 18.01	5/2	60.2 ± 9.0	14.4 ± 9.3

*Significantly higher for subjects without upper-limb impairment than for those with upper-limb impairment ($p < 0.02$).

attached to a hang weight carriage so that precise loads could be applied. Weights were then added to the carriage to provide the desired resistance to the turning of the flywheel.

We measured gas exchange using a microprocessor, which interfaced a zirconium oxygen analyzer, infrared carbon dioxide analyzer, and pneumotachometer for computation of inspired and expired ventilator volumes based on breath-by-breath flow-volume loops. Before each JUMP and continuous work rate exercise test, gas analyzers were infused with known mixtures of oxygen and 5 percent carbon dioxide in a nitrogen medium for calibration. We calibrated the pneumotachometer by injecting room air from a 3 L gas syringe at various flow rates. The subject was connected to the system by wearing a mouthpiece attached to the analyzers and pneumotachometer by plastic tubing. We computed oxygen consumption (VO_2) breath by breath using the standard Haldane transformation [35]. Respiratory exchange ratio was determined as the volume of expired carbon dioxide divided by oxygen uptake.

We monitored heart rate (HR) continuously by using a telemeter pulse monitor or by hardwired electrocardiograph (EKG). In the single stage test, measurements were obtained with the use of an identical apparatus. Exercise training was done with elastic bands that were attached to nylon straps and fixed stationary by closing them on either side of a doorframe in a position that allowed simulated wheelchair propulsion.

Procedures

Exercise Testing

Following calibration of the analyzers and the informed consent procedure, subjects were prepared by placement of the telemeter HR monitor on the chest or application of EKG electrodes in the Mason-Liker 12-lead configuration. After the mouthpiece and a nose clip were positioned to prevent nasal ventilation, subjects rested for 6 minutes in the sitting position. Resting data were then recorded. After the rest interval, subjects began wheeling the ergometer at a speed of 32 rpm with no load added to the weight carriage. To maintain the 32 rpm designated speed, the subject watched a speedometer while the testing staff monitored closely. Using a JUMP protocol [36], the testing staff then added weight to the carriage in consistent increments at 1 min time intervals until the subject could no longer maintain the designated 32 rpm speed, despite strong encouragement from the investigational team. Weight increments were established such that volitional exhaustion would occur between approximately 6 to 12 min of resisted propulsion. Gas exchange and HR data were recorded during the last 30 s of each of the work stages and at volitional exhaustion. Similar peak exercise testing procedures were followed before conditioning, at 6 weeks, and after 12 weeks of conditioning.

Constant work rate tests were conducted following a rest interval of at least 30 min after completion of the JUMP tests. Resistance for the constant work rate endurance tests was calculated as 60 percent of the highest resistance attained on the pretraining JUMP test. Analyzer calibration and subject preparation were performed in the same manner as the JUMP test. Following 6 min of sitting rest, subjects began wheeling the ergometer at 32 rpm and zero resistance load. After a 3 min unloaded warm-up period, the resistance was added to the carriage and subjects propelled the ergometer at 32 rpm. Propulsion continued until the subject became too fatigued to sustain the designated speed, despite strong encouragement. Gas exchange and HR data were recorded every 30 s and at volitional exhaustion. Average VO_2 (VO_{2av}) was determined as the sum of the oxygen consumed over the entire constant work rate test divided by the endurance time (time from test onset to volitional exhaustion). Gross metabolic economy for the exercise bout was calculated as

$$\text{Economy} = [\text{total energy expenditure (kcal)/energy requirement (kcal)}] \times 100.$$

We determined total oxygen use by summing 30 s averages of VO_2 over the duration of the constant work rate endurance test. Similar endurance testing procedures were followed before beginning, after 6 weeks, and upon completion of the 12-week conditioning regimen.

Home Exercise Training Program

Following the JUMP and constant work rate endurance tests, subjects participated in a 12-week exercise-conditioning program using simulated resisted propulsion as the method of perturbation. After informed consent, all subjects were provided an orientation session that included instruction in the simulated-resisted propulsion exercise program, including warm-up, muscle endurance and aerobic exercise participation, practice in all aspects of the exercise program, and cooldown. An exercise

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evaluation was also completed so that appropriate resistances could be determined and compliance with appropriate exercise intensity procedures could be ensured. For their safety, subjects were instructed on which clinical signs and symptoms they should be aware and on how to maintain their training logs. Monitoring of the exercise training program occurred during biweekly sessions in which the training logs were reviewed with the subjects and the exercise program was evaluated for the need for progression of the resistance to maintain the target HR. The exercise program consisted of upper-limb stretching, followed by 812 repetitions of maximally resisted simulated propulsion, followed by 20 min of aerobic exercise. The method of aerobic exercise consisted of attaching a series of therapeutic elastic bands to a nylon strap-fixed structure, such as wedging them between a closed door and a doorframe. The bands were positioned so that the subject could sit in her or his wheelchair, with wheels in the locked position, and simulate the propulsion motion as the bands were stretched and relaxed continuously (**Figure 1**). Handles were attached to the elastic bands to provide a structure for gripping (subjects with upper-limb impairment modified their grip according to their ability but no subject needed assistance to grip the handles).

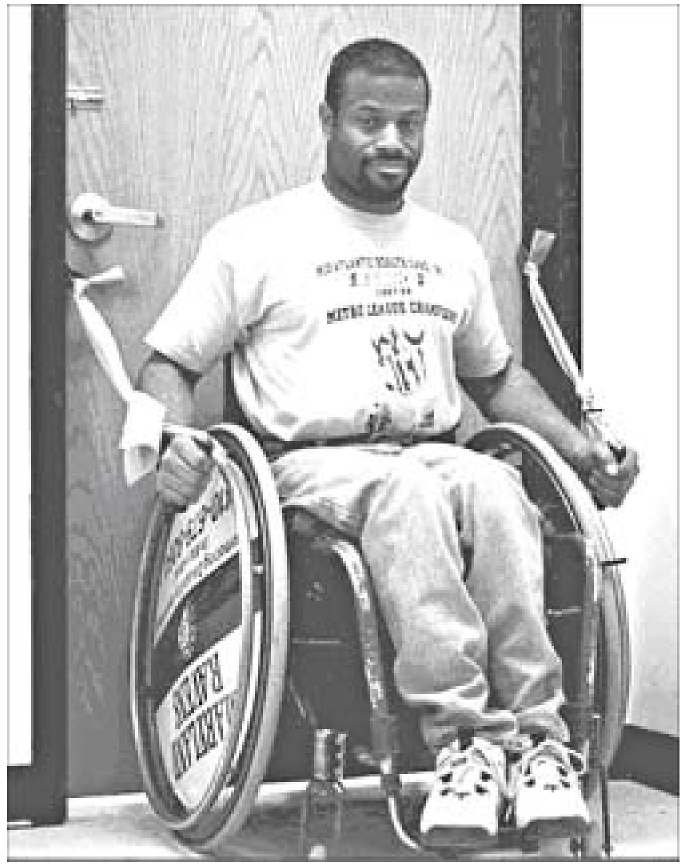

Figure 1.
Subject demonstrating in-home arrangement for performing aerobic exercise. Elastic bands were positioned so exercise movement approximates wheelchair propulsion. Note handles attached to elastic bands for gripping by all subjects.

We were able to regulate the intensity of the muscle endurance portion by selecting several elastic bands that varied in stretch resistances from low to medium to high (Theraband™), which resulted in exhaustion between 8 to 12 repetitions. We determined the stretch resistance for the aerobic exercise portion by selecting elastic bands from a range of low, medium, and high resistances that would attain the target intensity when the band was repeatedly stretched and relaxed at a rate of 1 c/s. For both muscle endurance and aerobic conditioning, resistance was applied throughout subjects' entire range of motion used for manual wheelchair propulsion.

After initial methodological training in the laboratory, subjects performed the exercise program at home, with one session supervised in the laboratory every other week. We evaluated and altered both muscle endurance and aerobic conditioning procedures to maintain the designated intensities at biweekly sessions in the laboratory. During the biweekly sessions, when subjects could complete 13 repetitions on the muscle endurance portion of the program, the stretch resistance was increased to reduce the maximum repetitions again to between 8 and 12. The stretch band resistance for aerobic conditioning was increased to maintain the target HR at a stretch rate of 1 c/s. Adherence to the program was tracked by careful review of the daily exercise session logs, and reasons for missed sessions were examined and discussed with the subjects during the biweekly visits to the exercise laboratory. To closely regulate the exercise stimulus dosage, we dismissed subjects not able to complete 90 percent of the 36 sessions from the study.

Statistics

Dependent variables were compared at the preconditioning, 6-week, and 12-week data collection points (first main effect) with the use of two-way repeated measures analyses of variance (ANOVA) and the general linear models procedure of the Statistical Analysis System (SAS). The analyses also determined if significant differences in the dependent variables occurred because of having or not having upper-limb impairment (second main effect—unequal group analysis based on general linear models) and if these differences varied by group across the 12-week conditioning procedure (interaction effect). The dependent variables for these analyses were peak power output (PO), VO_2, and HR. We calculated intraclass correlation coefficients (ICCs) (*R*) as the quotient of the difference in subject and within factor mean squares divided by the subject mean square to determine the compartmental stability of the ratio of the true interindividual bias to the experimentwise bias across the 12-week time span. Endurance test results were also compared across the training regimen and in both groups. We again used two-way repeated measures ANOVAs to determine significant differences in the dependent variables among the tests and groups, as just described. Dependent variables for the endurance test analyses were test duration, defined as the total time the exercise was sustained; VO_{2av}; total work calories; and gross metabolic economy. We used analysis of covariance (endurance time as covariate) to determine if changes in total work calories persisted independently of changes in endurance time.

Separate intragroup, one-way ANOVAs were also calculated to examine intragroup trends further when intergroup trends did not interact with them significantly. We again used ICCs (*R*) to determine statistical stability of the test by group measures.

Significant differences were determined at $p < 0.05$. An *R*-value of 0.60 or greater was accepted as sufficient for determination of acceptable stability (high stability = $R > 0.80$) and, in the absence of significant intratest differences, reliability. Intergroup visual comparisons were also made when the necessary and sufficient sample size was too small to facilitate an accurate interpretation of statistical trends. Data are presented as means and standard deviations (SDs) throughout the text and tables. Confidence intervals (CIs) and standard error of measurement (SEM) scores were also calculated and reported in units corresponding to mean score units for each of the dependent variables.

RESULTS

Body weight was significantly higher ($p < 0.0200$) in the subjects without upper-limb impairment than in those with impairment (**Table 1**). The group with upper-limb impairment (28.6%) consisted of a slightly higher proportion (chi-square; $p < 0.0500$) of females than the group without upper-limb impairment (23.8%). A significant difference in the number of years spent in a wheelchair as the primary mode of ambulation was not observed.

Significant group-by-test interactions were not observed. Significant main effect differences in peak HR, VO_2, and PO were not observed for the baseline, 6-week and 12-week peak exercise tests. As expected, peak VO_2 and peak PO were significantly higher in the subjects without upper-limb impairment than in those who had impairment (**Table 2**). ICCs were acceptable for measurements of peak HR, peak VO_2, and peak PO, and the absence of significant *F*-ratios for these analyses indicated that the measurements were reliable. SEMs were generally small for peak HR, VO_2, and PO, as were the associated CIs (**Table 3**).

Endurance time was not significantly different for either the subjects with or without upper-limb impairment (**Table 4**). Total work calories were significantly higher for subjects with upper-limb impairment than for those without upper-limb impairment. Total work calories

Table 2.
Peak measures (mean + 1 SD) of HR, VO_2, and PO achieved during JUMP test by subjects with and without upper-limb impairment.

Variable	No Upper-Limb Impairment			Upper-Limb Impairment		
	Baseline	6 Weeks	12 Weeks	Baseline	6 Weeks	12 Weeks
HR (bmp)	148 ± 26	140 ± 23	137 ± 19	137 ± 32	134 ± 26	133 ± 27
VO_2 (mL/min)*	1,126 ± 363	1,113 ± 302	1,115 ± 308	866 ± 323	828 ± 281	871 ± 321
PO (W)*	87 ± 43	91 ± 37	87 ± 43	34 ± 26	31 ± 29	39 ± 26

*Main effect significantly higher for those without upper-limb impairment than for those with upper-limb impairment ($p < 0.001$).
VO_2 = oxygen consumption
PO = power output
HR = heart rate
bpm = beats per minute

Table 3.
95% confidence intervals (95% CI), standard error of measurement (SEM), and intraclass correlation coefficients (*R*-values) for measurements obtained during JUMP (peak exercise) and continuous work rate endurance tests.

Variable	95% CI*	SEM	*R*-Value
Peak Exercise Measurements			
VO_2 (mL/min)	1004.5 to 1089.4	82.5	0.97
PO (W)	88.8 to 105.7	15.33	0.94
HR (bpm)	121.0 to 157.0	17.4	0.74
Continuous Work Rate Endurance Measurements			
Endurance Time (min)	25.9 to 30.8	2.69	0.89
Average VO_2 (mL/min)	619.5 to 677.6	77.2	0.95
Metabolic Economy (%)	18.0 to 19.6	2.45	0.95
Total Work Calories (kcal)	88.8 to 105.7	55.7	0.93

VO_2 = oxygen consumption
PO = power output
HR = heart rate
bpm = beats per minute
*95% CI calculated for small samples based on t-distributions.

Table 4.
Averages (+1 SD) for endurance time (min) and average VO_2 over the continuous work rate tests (mL/min), gross metabolic economy (%), and total work calories (kcal) during the continuous work rate endurance tests in subjects with and without upper-limb impairment.

Variable	No Upper-Limb Impairment*			Upper-Limb Impairment		
	Baseline	6 Weeks	12 Weeks	Baseline	6 Weeks	12 Weeks
Endurance Time (min)*	25.0 ± 5.9	30.1 ± 9.0	32.5 ± 10.0	20.4 ± 8.8	23.9 ± 16.0	31.2 ± 27.6
Average VO_2 (mL/min)*	688 ± 247	698 ± 218	698 ± 195	501 ± 174	522 ± 166	553 ± 195
Metabolic Economy*	22.1 ± 06.6	21.3 ± 05.9	21.7 ± 07.4	11.5 ± 06.9	10.0 ± 07.5	12.3 ± 06.4
Total Work Calories*	89.8 ± 50.2	113.1 ± 65.0	120.6 ± 65.7	51.9 ± 30.8	58.2 ± 38.5	78.0 ± 57.4

*Subjects with upper-limb impairment significantly lower than subjects with no upper-limb impairment independent of week of measurement (two-way ANOVA main effect; $p < 0.05$).
VO_2 = oxygen consumption

increased after 6 weeks of conditioning and again after 12 weeks ($p < 0.05$) as a main effect whether the subjects had or did not have upper-limb impairment (**Figure 2**). Endurance test duration was significantly increased ($p < 0.0122$) after 12 weeks of conditioning (**Figure 2**), also as a main effect irrespective of grouping. VO_{2av} ($p < 0.0001$) and gross metabolic economy ($p < 0.0001$) were lower in the subjects with upper-limb impairment than in those without upper-limb impairment. Significant differences in VO_{2av} and metabolic economy were not observed as a result of the exercise conditioning regimen. No significant interactions of group and test were observed for the continuous work rate tests. Measurements for VO_{2av}, endurance time, and metabolic economy were statistically stable (**Table 3**). Again, SEMs and CIs were small. The intragroup trends were analyzed separately for the dependent variable endurance time because of the small subset (n = 7) in the group with upper-limb impairment. This analysis revealed that the group without upper-limb impairment improved significantly and ($p > 0.01$) the group with impairment had no observed improvement. These separate ANOVAs indicated that the small number of subjects in the upper-limb subset was insufficient for overcoming the experimentwise variance. Because these results were accepted with high reliability ($R > 0.80$) and the sample was too small to permit interpretation of a nonsignificant F-ratio in the group with upper-limb impairment, a visual analysis of the data was determined to be appropriate. This analysis revealed that most of the improvement in endurance time was observed by the end

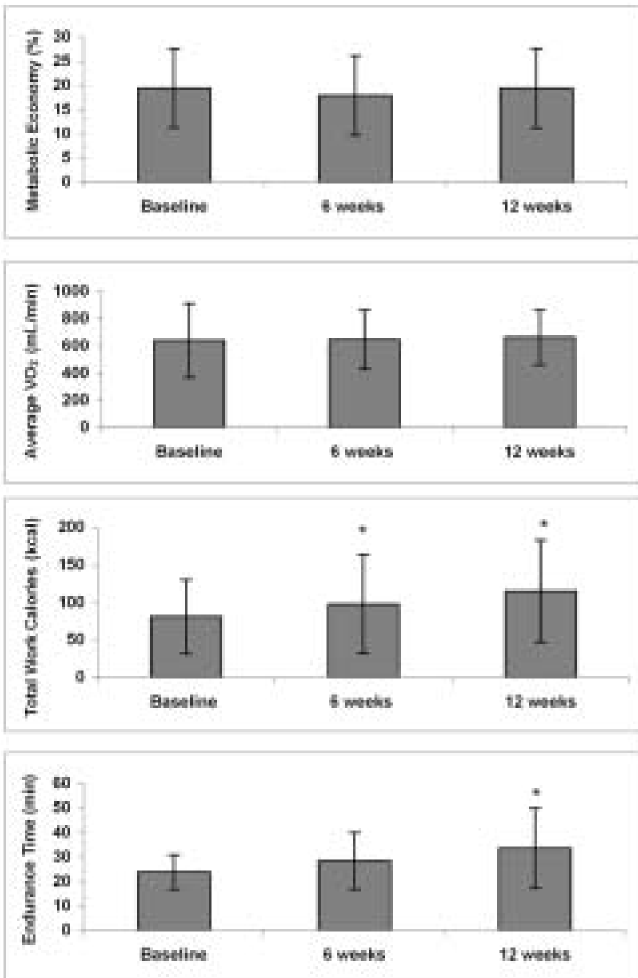

Figure 2.
Gross metabolic economy, average VO_2, total work calories, and endurance time at baseline, 6 weeks, and 12 weeks of exercise conditioning. ★Indicates significant difference from previous data-time point ($p < 0.05$).

of 6 weeks (test 2) in the group without upper-limb impairment, while in the group with upper-limb impairment, most of the improvement occurred between 6 and 12 weeks. Even though the preconditioning endurance time appeared to be substantially lower for the group with upper-limb impairment than for the group without impairment, endurance time was nearly identical for the two groups after 12 weeks of training.

DISCUSSION

Findings of this study indicated that overall cardiorespiratory endurance was higher in those without upper-limb impairment compared to those with impairment. Endurance was increased by the training regimen, despite that peak VO_2 did not improve. Visual analysis of the data revealed that the group with upper-limb impairment required a substantially longer period of training to induce increases in endurance compared to the group without upper-limb impairment. By week 12, those with upper-limb impairment had endurance times that were almost identical to those without upper-limb impairment. The results of this study were important because the 12th week of participation in the simulated propulsion exercise protocol improved wheelchair ergometer endurance in a heterogeneous group of manual wheelchair users. Visualization of the results further suggested that conditioning might take longer for those with upper-limb impairment. Also suggested is that prolonged conditioning may increase endurance in manual wheelchair users who have an upper-limb impairment to levels that are nearly identical to those observed in manual wheelchair users who do not have upper-limb impairment. The increase in endurance was observed without an increase in peak VO_2, irrespective of the presence or absence of upper-limb impairment.

Cardiorespiratory function has been well established as the product of oxygen delivery, as measured by cardiac output, and as tissue oxygen extraction, as measured by arteriovenous oxygen difference [32,35]. Arteriovenous oxygen difference has been determined to be the result of tissue capillarity density and oxidative enzyme content of the peripheral tissue. Studies in an animal exercise conditioning model have demonstrated that, while both of these factors exerted some influence on both peak VO_2 and the time a bout of exercise could be sustained, changes in cardiac output and arteriovenous oxygen difference may have exerted specific effects on peak VO_2 and cardiorespiratory endurance [32,37,38]. For example, peak VO_2 has been known, under physiologic conditions, to correlate highly with peak cardiac. However, studies in the animal model have revealed more modest relationships between cardiac output and endurance (defined as the time that exercise can be sustained, such as on a continuous work rate test). Conversely, the concentration of selected mitochondrial oxidative enzymes are closely related to endurance but only modestly related to cardiac output.

Low- to moderate-intensity exercise conditioning has been demonstrated to increase arteriovenous difference with variable effects on cardiac output [39,40], whereas higher intensity aerobic exercise has been demonstrated to improve both cardiac output and arteriovenous difference

[39,40]. Subjects in this study routinely used manual wheelchair propulsion for ambulation and so may have already been conditioned to the propulsion task. The target HR of 60 percent of the measured peak HR represented a low to moderate exercise intensity, particularly for these experienced wheelchair users. The training regimen was insufficient for producing consistent increases in peak VO_2, while resulting in improvements in endurance in these manual wheelchair users. Cardiac output, arteriovenous oxygen difference, and oxidative enzyme concentrations were not measured in this study. However, when interpreted in light of the reviewed literature, the results of this study may have suggested that improvement in the muscles' ability to extract and use oxygen may have resulted from the exercise regimen. Therefore, results of the current study suggest that enzymatic and respiratory adaptations in the peripheral tissues (trained skeletal muscles) may have been a mechanism for the improved cardio respiratory endurance, as evidenced by increased endurance time. The results underscore a need for further investigation of the relative contributions of cardiac output and arteriovenous oxygen difference to wheelchair propulsion endurance in manual wheelchair users. Reasons for the observed improvements may have also included increased tolerance of perceived exertion and other motivational or learning influences.

The reliability of cardiorespiratory measurements made during endurance testing on the wheelchair ergometer has been established in nondisabled subjects [41]. In the current study, reliability of these measurements was determined to be high in manual wheelchair users who used the wheelchair as their main mode of ambulation. Measurement error was determined to be low. Thus, neither the true intersubject variance nor the measurement bias appeared to be the reason that significant differences in cardiorespiratory measurements, such as VO_2 were not observed. Results of the current study and those of a previous investigation have suggested that maximum graded exercise testing was insufficient for assessing cardiorespiratory endurance in manual wheelchair users [34]. The continuous work rate endurance tests appeared to have provided more robust determinations of cardiorespiratory fitness than measures of peak VO_2 and peak PO in these manual wheelchair users [34].

Forty-eight manual wheelchair users were medically screened, gave informed consent, and began the conditioning regimen. Data were insufficient for analysis in seven of these subjects. Reasons for exclusion of these data were uncertainty of the subjects attaining volitional exhaustion and equipment failure on one or more tests. Three subjects were seropositive for Human Immunodeficiency Virus (HIV) infection and were using nucleoside analog medication. New information became available late in the project that functional aerobic impairment is prevalent in people with HIV, most likely because of nucleoside analog therapy [33]. This finding resulted in exclusion of the data obtained from subjects with HIV seropositivity from the analyses. Of the remaining 38 subjects, 10 were excluded as a result of not completing 90 percent of the exercise sessions. Thus, 28 subjects (21 without upper-limb impairment and 7 with upper-limb impairment), or 58.3 percent of the participants, completed the conditioning protocol with 90 percent adherence to the protocol and had data acceptable for the analyses. The high 90 percent adherence requirement was maintained to control for the bias potentially introduced by the dose response variation that could have been introduced by lower levels of adherence, particularly with this small sample size.

In general, the sample was a convenience sample and was not randomly assigned to groups, the number of dropouts would not have increased the size of the sample to a level of sufficiency in both groups, and data were insufficient for extrapolation to predict training outcomes. Neither was an a priori design considered to include those not complying with the training regimen nor was the post-training exercise testing completed when subjects dropped out or excluded for noncompliance. Thus, intent to treat analysis could not be conducted because of the failure of the research design to meet the underlying assumptions for this type of analysis, as well as insufficient data for measuring the intent to treat. Therefore, data were also insufficient for determining if observations made on the 11 program dropouts were dissimilar to data obtained from those completing the training regimen.

The influences of age and gender on oxidative metabolic capacity and exercise performance have been well documented. In the current study, the proportion of females was 13 percent higher in the group with upper-limb impairment than in those without upper-limb impairment. Conversely, the group without upper-limb impairment was 7 years (19%) older than the group with upper-limb impairment. These influences appeared to be offsetting with respect to interpretation of the results. If, in the by-gender analyses, confounding influences existed covertly, the total effect would have appeared to be conservative because of the larger intragroup variation in age compared to gender and the finding that the group without upper-limb impairment, those with the best performance, were older than the group with upper-limb impairment who had the worst performance.

CONCLUSIONS

The sample size of this study, particularly the group with upper-limb impairment, was small and heterogeneous with respect to the reasons for paralysis. Moreover, much of the interpretation of these results was based on visual analyses. Therefore the findings related to comparisons between manual wheelchair users with and without upper-limb impairment in this investigation were suitable only when delimited to this sample. Results of the study did however reveal that a simulated wheelchair propulsion-conditioning regimen of low intensity done in the wheelchair users home with minimal assistance could result in improved resistance to fatigue.

REFERENCES

1. Cardus D, Ribas-Cardus F, McTaggart WG. Coronary risk in spinal cord injury: assessment following a multivariate approach. Arch Phys Med Rehabil 1992;73:930–33.
2. Bauman WA, Spungen AM, Raza M, Rothstein J, Zhang RL, Zhong YG, et al. Coronary artery disease: metabolic risk factors and latent disease in individuals with paraplegia. Mt Sinai J Med 1992;59:163–68.
3. Weld KJ, Wall BM, Mangold TA, Steere EL, Dmochowski RR. Influences on renal function in chronic spinal cord injured patients. J Urol 2000;164:1490–93.
4. Bauman WA, Adkins RH, Spungen AM, Waters RL. The effect of residual neurological deficit on oral glucose tolerance in persons with chronic spinal cord injury. Spinal Cord 1999;37:765–71.
5. Dalyan M, Cardenas DD, Gerard B. Upper extremity pain after spinal cord injury. Spinal Cord 1999;37:191–95.
6. Sinnott KA, Milburn P, McNaughton H. Factors associated with thoracic spinal cord injury, lesion level and rotator cuff disorders. Spinal Cord 2000;38:748–53.
7. Nyland J, Quigley P, Huang C, Lloyd J, Harrow J, Nelson A. Preserving transfer independence among individuals with spinal cord injury. Spinal Cord 2000;38:649–57.
8. Subbarao JV, Klopfstein J, Turpin R. Prevalence and impact of wrist and shoulder pain in patients with spinal cord injury. J Spinal Cord Med 1995;18:9–13.
9. Paffenbarger RS Jr, Lee IM. Physical activity and fitness for health and longevity. Res Q Exerc Sport 1996;67:S11–28.
10. Lee IM, Skerrett PJ. Physical activity and all-cause mortality: what is the dose-response relation? Med Sci Sports Exerc 2001;33:S459–71,S493–94.
11. LaMonte MJ, Durstine JL, Addy CL, Irwin ML, Ainsworth BE. Physical activity, physical fitness, and Framingham 10-year risk score: the cross-cultural activity participation study. J Cardiopulm Rehabil 2001;21:63–70.
12. Kampert JB, Blair SN, Barlow CE, Kohl HW 3rd. Physical activity, physical fitness, and all-cause and cancer mortality: a prospective study of men and women. Ann Epidemiol 1996;6:452–57.
13. Erikssen G, Liestol K, Bjornholt J, Thaulow E, Sandvik L, Erikssen J. Changes in physical fitness and changes in mortality. Lancet 1998;352:759–62.
14. DiPietro L. Physical activity in aging: changes in patterns and their relationship to health and function. J Gerontol A Biol Sci Med Sci 2001;56 Spec No. 2:13–22.
15. Blair SN, Kohl HW 3rd, Paffenbarger RS Jr, Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality. A prospective study of healthy men and women. JAMA 1989;262:2395–401.
16. Blair SN, Kohl HW 3rd, Barlow CE, Paffenbarger RS Jr, Gibbons LW, Macera CA. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. JAMA 1995;273:1093–98.
17. Church TS, Kampert JB, Gibbons LW, Barlow CE, Blair SN. Usefulness of cardiorespiratory fitness as a predictor of all-cause and cardiovascular disease mortality in men with systemic hypertension. Am J Cardiol 2001;88:651–56.
18. Baan CA, Feskens EJ. Ned Tijdschr Geneeskd [Prevention of diabetes mellitus type 2] 2001;145:1677–80.
19. Bart F, Verkindre C. Rev Mal Respir [Physical activity and public health] 2001;18:S43–45.
20. Bjornholt JV, Erikssen G, Liestol K, Jervell J, Erikssen J, Thaulow E. Prediction of Type 2 diabetes in healthy middle-aged men with special emphasis on glucose homeostasis. Results from 22.5 years' follow-up. Diabetes Med 2001; 18:261–67.
21. Sato Y. Diabetes and life-styles: role of physical exercise for primary prevention. Br J Nutr 2000;84 Suppl 2:S187–90.
22. Wei M, Schwertner HA, Blair SN. The association between physical activity, physical fitness, and type 2 diabetes mellitus. Compr Ther 2000;26:176–82.
23. Drake DA. A longitudinal study of physical activity and breast cancer prediction. Cancer Nurs 2001;24:371–77.
24. Thune I, Furberg AS. Physical activity and cancer risk: dose-response and cancer, all sites and site-specific. Med Sci Sports Exerc 2001;33:S530–50,S609–10.
25. Yancey AK, Miles OL, McCarthy WJ, Sandoval G, Hill J, Leslie JJ, et al. Differential response to targeted recruitment

strategies to fitness promotion research by African-American women of varying body mass index. Ethn Dis 2001; 11:115–23.

26. Lee IM, Rexrode KM, Cook NR, Hennekens CH, Burin JE. Physical activity and breast cancer risk: the Women's Health Study (United States). Cancer Causes Control 2001; 12:137–45.
27. Shephard RJ, Shek PN. Associations between physical activity and susceptibility to cancer: possible mechanisms. Sports Med 1998;26:293–315.
28. Woods JA. Exercise and resistance to neoplasia. Can J Physiol Pharmacol 1998;76:581–88.
29. Noreau L, Proulx P, Gagnon L, Drolet M, Laramee MT. Secondary impairments after spinal cord injury: a population-based study. Am J Phys Med Rehabil 2000;79:526–35.
30. Noreau L, Fougeyrollas P. Long-term consequences of spinal cord injury on social participation: the occurrence of handicap situations. Disabil Rehabil 2000;22:170–80.
31. Noreau L, Shephard RJ. Spinal cord injury, exercise and quality of life. Sports Med 1995;20:226–50.
32. Brooks G, Fahey T, White T, Baldwin K. Exercise physiology: Human bioenergetics and its applications. Mountain View (CA): Mayfield Publishing Company; 2000. p. 851.
33. Rodgers MM, Keyser RE, Gardner ER, Russell PJ, Gorman PH. Influence of trunk flexion on biomechanics of wheelchair propulsion. J Rehabil Res Dev 2000;37:283–95.
34. Keyser RE, Rodgers MM, Gardner ER, Russell PJ. Oxygen uptake during peak graded exercise and single-stage fatigue tests of wheelchair propulsion in manual wheelchair users and the able-bodied. Arch Phys Med Rehabil 1999;80:1288–92.
35. Robergs R, Roberts S. Exercise physiology: exercise, performance, and clinical applications. St. Louis (MO): Mosby; 1997. p. 137, 840.
36. Rasche W, Janssen TW, van Oers CA, Hollander AP, van der Woude LH. Responses of subjects with spinal cord injuries to maximal wheelchair exercise: comparison of discontinuous and continuous protocols. Eur J Appl Physiol Occup Physiol 1993;66:328–31.
37. Davies KJ, Packer L, Brooks GA. Exercise bioenergetic following sprint training. Arch Biochem Biophys 1982; 215(1):260–65.
38. Davies KJ, Packer L, Brooks GA. Biochemical adaptation of mitochondria, muscle, and whole-animal respiration to endurance training. Arch Biochem Biophys 1981;209:539–54.
39. Paterson DH, Shephard RJ, Cunningham D, Jones NL, Andrew G. Effects of physical training on cardiovascular function following myocardial infarction. J Appl Physiol 1979;47:482–89.
40. Seals DR, Hagberg JM, Hurley BF, Ehsani AA, Holloszy JO. Endurance training in older men and women. I. Cardiovascular responses to exercise. J Appl Physiol 1984;57(4): 1024–29.
41. Keyser RE, Rodgers MM, Rasch ER. Reliability of cardiorespiratory measurements during wheelchair ergometry. J Rehabil Res Dev 2001;38:423–30.

Submitted for publication January 4, 2002. Accepted in revised form July 7, 2003.