Scand J Rehab Med 12: 61–65, 1980

THE EFFECTS OF PHYSICAL TRAINING ON HIGH LEVEL SPINAL LESION PATIENTS

G. C. Gass, J. Watson, E. M. Camp, H. J. Court, L. M. McPherson and P. Redhead

From the School of Physiotherapy and Department of Biological Sciences, Cumberland College of Health Sciences, Lidcombe, N. S. W. 2141, Australia

ABSTRACT. Seven chronically institutionalised high level spinal lesion subjects participated in an exercise program, five days per week for seven weeks. Anthropometry, spirometry and maximum oxygen consumption ($\dot{V}_{O_2}$ max) was measured initially and at the end of seven weeks. Subjects generally followed a common training program. No significant changes were noted in the anthropometric and spirometric measurements. A significant increase (34%) in minute ventilation was recorded, and this was accompanied by significant increases in $\dot{V}_{O_2}$ max 0.764 ± 0.341 to 1.03 ± 0.419 $l \cdot min^{-1}$ ($P<0.01$) and wheelchair treadmill time 502 ± 340 to 766 ± 249 sec ($P<0.05$). The exercise program had no significant effect on maximum or recovery heart rates. Many subjects had subjective comments on improved psychological state. The significant changes in $\dot{V}_{V_2}$ max, $\dot{V}_E$, and wheelchair treadmill time indicated that high level spinal lesion subjects can exhibit an improved cardiovascular function through regular aerobic exercise.

It is well established that a spinal cord lesion results in a decrement in physical work capacity of the individual (1, 13) and that physical training programs for disabled persons can result in an increase in maximum oxygen consumption (12, 13), a decrease in heart rate at a given work rate (4), an increase in arm work capacity (3, 4, 8, 12) and an increased feeling of well being (2,10). The extent of these physiological changes may be very much dependent upon the level of spinal cord lesion.

Many of the previous studies have investigated the acute and chronic physiological and psychological effects of exercise in low level spinal lesion subjects; however, little data has been gathered on the effects of chronic exercise on institutionalized high level spinal cord lesion subjects.

With sport and regular exercise now playing a larger role in the rehabilitative process after spinal cord trauma, it is essential to understand the extent of the physiological gain, relative to the initial level, that can be experienced in high level spinal cord lesion subjects as a result of chronic exercise. With this in mind, the present study investigated the physiological effects of a chronic exercise program on institutionalized high level spinal cord lesion subjects.

METHODS

Nine patients with a high level spinal lesion volunteered to participate in a 7-week physical training program. All subjects were permanent residents in a spinal unit of a government funded hospital.

Each individual, prior to beginning the pre-test phase of the program, underwent a medical examination with particular attention to the cardiovascular system.

Subjects were requested to make two visits to the laboratory to fulfill the requirements of the pre-test phase. During the first visit subjects were familiarized with the treadmill, mouth piece, head gear and measurement procedures in an attempt to lessen anxiety about the maximum wheelchair treadmill test and subsequent measurement and training procedures. When the subjects had learnt to push and control their chairs on the treadmill a second visit was arranged.

On the second visit subjects were weighed to the nearest 0.1 kg on a modified chair on a set of clinical scales and the net body weight was obtained by applying the

Table I. *Clinical and general characteristics of the subjects*

Subject	Age (y./mo.)	Time in chair (y.)	Level of lesion	Cause of injury	Spasm
1	27/10	8	T_4	Fall	+
2	28/0	11	C_{5-6}	Wrestling	+
3	40/3	18	C_6[a]	Army training	+
4	50/2	14	T_1	M.V.A.[b]	+
5	47/3	17	C_{5-6}	Diving	+
6	25/1	9	T_1	M.V.A.[b]	+
7	24/3	5	C_{5-6}	Diving	+

[a] Incomplete spinal cord lesion.
[b] Motor vehicle accident.

Table II. *Anthropometry of high level spinal lesion subjects*

	Pre-test			Post-test		
	Mean	S.D.	Range	Mean	S.D.	Range
Weight (kg)	82.11	14.56	68.2–115	83.33	13.81	71.4–115.0
Height (cm)	174.4					
Chest circum. (cm)	104.3	8.8	90–120	105	9.9	91–120
Waist circum. (cm)	109.6	12.2	91–127	113.7	16.8	87–139
Arm circum. (cm)	33	4	28–38	33	3	29–38
Skinfolds						
Triceps (mm)	16.1	6.7	8–30	13.7	7.3	7–30
Subscap. (mm)	17.1	10.6	7–41	15.8	11.4	7–42
Suprailiac (mm)	20.4	12.3	8–45	18.8	11.6	8–45
Total (mm)	53.6	31.2	34–116	48.3	31.8	27–117

appropriate correction factor for the weight of the chair. Lying height, measured to the nearest 0.1 cm, was obtained by placing the subject horizontally on a Holtain table. Body circumferences were measured with a Lufkin steel tape to the nearest millimetre. The chest, waist and arm circumferences were measured just superior to the nipple line, at the level of the umbilicus and at a point half way down the humerus respectively.

To estimate adiposity, skinfold thicknesses were measured at three sites, subscapular, suprailiac and triceps, and summated in accordance with standardized procedures (5). A dry bellows vitalograph was used to measure forced vital capacity (FVC) and forced expiratory volume in one second ($FEV_{1.0}$) from which FEV% was calculated. Duplicate spirometry was performed in the sitting position with a nose clip and corrected to BTPS. Duplicate peak expiratory flow rates (PEFR) were determined with a Wright's peak flow meter and the highest value recorded.

Maximum oxygen consumption was obtained by having the subject push his wheelchair on a motor driven treadmill. After an initial two minutes at 2.0 $km \cdot h^{-1}$ and zero gradient, the gradient was increased by 2%. After a further two minutes the speed was increased by 0.5 $km \cdot h^{-1}$. Alternate changes in gradient and speed continued every two minutes until the gradient reached 6%, at which time further increases in work rate were met by increases in speed alone. The subject followed this protocol until exhaustion or electrocardiographic changes precluded further work. In order that the alignment of the wheelchair on the treadmill could be maintained, particularly at the higher work rates, restraining leather straps were provided. Subjects were requested to maintain a strike rate and/or wheelchair thrust so that the straps remained tension free.

Subjects breathed through a low resistance valve (Hans Rudolph no. 2600) and expired air was passed through an ice cooled mixing chamber before passing through a tissot calibrated Parkinson Cowan (CD4). Paramagnetic oxygen and infrared carbon dioxide analysers continuously sampled expired air from the ice cooled mixing chamber. Each analyser was calibrated frequently with mixtures of chemically analysed gas. Calculations were made each minute throughout the treadmill test of oxygen consumption ($\dot{V}_{O_2}$ $l \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot min^{-1}$) ventilation corrected to STPD ($\dot{V}_E$STPD $l \cdot min^{-1}$) and respiratory exchange ratio (R) using a PDP 11/10 analogue computer. Heart rate was monitored continuously from a V_5 lead and recorded pre-exercise, during the last 10 seconds of each minute of exercise and for one minute post exercise. The criterion employed to terminate the treadmill test was whichever came first of the following: 1) the subject could push his wheelchair no further; 2) the restraining straps remained tight for 5 consecutive wheelchair strikes; 3) electrocardiographic abnormalities.

Subjects having successfully completed the pre-test, trained where possible five days per week for seven weeks. Each trained by pushing his wheelchair on a motor driven treadmill. After an initial five minutes at 2.5 $km \cdot h^{-1}$ and zero gradient, alternate increases in gradient and speed occurred every five minutes until exhaustion. The increases in gradient and speed were 2% and 0.5 $km \cdot h^{-1}$ respectively. Generally all subjects followed the outlined protocol, but on some occasions some individual variation was experienced because of personal and/or medical difficulties. During the training sessions each subject was closely supervised and encouraged to push his wheelchair as far as possible until fatigue precluded continued exercise. The time of the training session was recorded and the training distance calculated. The time and the distance was used not only to quantify the training but also as a motivating factor.

At the end of the 7th week the subjects underwent a post training test, which included the administration of the same pre-test procedures.

Descriptive statistics were calculated for all variables using standard statistical programs. A Student's t-test for related samples was used to test for significant differences between the pre-test and post test measurements. A p-value equal to or less than 0.05 was accepted as significant.

RESULTS

The first week of the training program saw the withdrawal of two subjects. The remaining 7 subjects adhered to the training program requirements, although previously scheduled surgery enabled two

Table III. *Spirometry of high level spinal lesion subjects*

	Pre-test			Post-test		
	Mean	S.D.	Range	Mean	S.D.	Range
$FEV_{1.0}$ (litre, BTPS)	2.57	0.98	1.3–4.0	2.38	1.01	0.95–3.85
FVC (litre, BTPS)	3.18	1.13	2.1–5.2	3.08	1.14	1.7–5.0
FEV%	80	12	62–96	76	13	50–90
PEFR ($l \cdot min^{-1}$)	365	103	194–510	372	105	175–525

of the seven subjects to complete only 6 weeks of the training program.

The clinical and general characteristics of the subjects are presented in Table I. The most frequently listed traumas were diving and motor vehicle accidents (MVA).

The anthropometric characteristics of the subjects are presented in Table II. There were no significant changes in the anthropometric characteristics of the subjects as a result of 7 week training program ($p>0.05$).

The spirometry results are presented in Table III. The 7 week training program produced no significant differences in the pre- and post-test spirometry ($p>0.05$). Three subjects were cigarette smokers, smoking from 10 to in excess of 60 cigarettes per day, and the high consumption of cigarettes (>60 day^{-1}) may have contributed to the low spirometry values in one smoker ($FEV_{1.0}$ 0.951 FVC 1.71 FEV% 50).

The physiological responses recorded during the maximum wheelchair treadmill test are presented in Table IV. The mean minute ventilation ($\dot{V}_E$) increased from 25.86±16.01 $l \cdot min^{-1}$ to 34.64±13.90 $l \cdot min^{-1}$; this 34% increase in maximum minute ventilation was significant at the $p<0.05$ level.

Over the 7 week training period the mean $\dot{V}_{O_2}$ max. ($ml \cdot kg^{-1} \cdot min^{-1}$ and $l \cdot min^{-1}$) increased by approximately 34% from 9.5±4.6 and 0.764±0.341 respectively at the pre-test to 12.7±5.9 and 1.03±0.419 respectively at the post-test, and this increase in $\dot{V}_{O_2}$ max. was highly significant ($p<0.01$)

Associated with the increase in $\dot{V}_{O_2}$ max. was an increased maximum wheelchair treadmill time. The post-test wheelchair treadmill time (766±249 sec) increased by 52% from the pre-test value (502±340) and this increase was significant ($p<0.05$).

The training program had no significant effects on increasing maximum heart rates or on decreasing recovery heart rates ($p>0.05$). The significant increase in oxygen consumption, minute ventilation and wheelchair treadmill time as a result of the training program indicated improved cardiovascular function.

DISCUSSION

The results of the present study indicate that high level spinal cord lesion subjects can improve their physical work capacity by a program of regular exercise. Prior to beginning the exercise training program, the subjects were permanent residents of a government funded spinal unit, and because of a variety of factors the subjects were unable to, or did not want to gain meaningful employment. As a re-

Table IV. *Physiological responses from maximum wheelchair treadmill test*

	Pre-test			Post-test		
	Mean	S.D.	Range	Mean	S.D.	Range
$\dot{V}_E$STPD ($l \cdot min^{-1}$)	25.86	16.01	10.77–61.53	34.64	13.90	21.72–64.87
$\dot{V}_{O_2}$ max. ($ml \cdot kg^{-1} \cdot min^{-1}$)	9.5	4.6	6.0–18.8	12.7	5.9	6.5–25.4
$\dot{V}_{O_2}$ max. ($l \cdot min^{-1}$)	0.764	0.341	0.41–1.42	1.03	0.419	0.75–1.94
HR max. ($b \cdot min^{-1}$)	125	26	101–187	129	19	114–173
HR Rec. ($b \cdot min^{-1}$)	106	18	80–134	106	22	66–130
Treadmill time (sec.)	502	340	70–967	766	249	360–1 080

sult of this situation, a significant proportion of their time was spent watching television and participating in gaming activities.

Numerous studies have demonstrated training adaptations in disabled persons (3, 11, 12, 13) although few of these studies have investigated the effects of chronic exercise on the cardiovascular function in high level spinal lesion patients.

The treadmill mode of training employed by the present study was designed to approximate the subjects' daily activities. Arm cranking while not being specific to daily activities, presents specific grip problems in the high level spinal lesion subject and to maximize the training effect, the treadmill was chosen as the ergometer. The use of a treadmill as a training ergometer was not without limitations. At an incline of 6% or greater the front wheels of the wheelchair tended to lift off the treadmill belt, placing the wheelchair in an unstable position and consequently increases in work rate had to be met by increases in speed. This method of increasing the work rate, while suitable for the low level spinal lesion subjects, was not suitable for the higher spinal lesion patients. The high spinal lesion patients could not move their arms back into a position of wheel thrust fast enough, so that the momentum gained in the preceding thrust was lost, and the restraining straps tightened, possibly assisting the wheelchair treadmill time.

The lack of significance in the anthropometrical measurements was not surprising since the daily training distance each subject pushed his wheelchair was approximately 900 m. In addition, each subject had available to him 3 hospital meals per day, together with supplemental snacks, so it was unlikely that a negative caloric balance was being experienced.

The maximum heart rate of those subjects with a spinal cord lesion T_1 and above was consistent with the values reported by others (5, 10, 15, 16). One subject with a T_4 lesion in the present group reached a maximum heart rate comparable to similarly aged able bodied individuals.

Overall the maximum heart rates were lower than other reported values (4, 8, 13, 17) and the values in the present study lend a measure of support to the suggestion that the cardiovascular regulatory functions are increasingly ineffective with higher spinal lesion because a large proportion of the sympathetic spinal control from supraspinal centres is absent (6).

The wheelchair treadmill time increased by approximately 52% and this significant increase was larger than findings of Knutsson et al. (10) who trained paraplegic and tetraplegic patients for 4–5 days per week for 6 weeks (10) and Pollock et al. (13) who trained predominantly paraplegics for 20 weeks.

While Knutsson et al. (10) found significant increases in performance time in paraplegics, their findings on performance time in tetraplegics are in disagreement with the present study.

Despite the significant increase in $\dot{V}_{O_2}$ max. as a result of the 7 week training program, the pre- and post-test maximum oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$); are lower than other values reported on disabled persons (11, 12, 13, 17). The low $\dot{V}_{O_2}$ max. in the present study is consistent with the level of spinal cord lesion and chronic inactivity. When the increase in $\dot{V}_{O_2}$ max. from the pre-test to the post-test is expressed as a percent (34%), the extent of the gain in $\dot{V}_{O_2}$ max. is larger than gains found in cerebral palsied children (2, 11), children with poliomyelitis (1), and other paraplegics (3, 12, 13).

The initial level of $\dot{V}_{O_2}$ max. is an important determinant of the percent gain in $\dot{V}_{O_2}$ max. (14) and the substantial gain in $\dot{V}_{O_2}$ max. together with the increased wheelchair treadmill time is probably a reflection of the low initial level of cardiovascular function of the present group.

The significant increase in ventilation in the present study, while consistent with the findings on poliomyelitic adolescents (1), is decidedly lower than ventilation values reported for other disabled groups (5, 13, 17). This low level of minute ventilation is the result of inadequate innervation of the intercostal and abdominal muscles, and years of chronic inactivity.

The level of spirometry, particularly in the cervical lesion subjects is lower than spirometric values in trained and sedentary paraplegics (8, 17), and internationally competing disabled athletes (9), and may be due to the interaction of three factors: (i) chronic inactivity, (ii) heavy cigarette smoking and (iii) loss of innervation to the intercostal and abdominal muscles.

The findings of the present study indicate that a regular exercise program over an extended period can significantly increase cardiovascular function in the chronically inactive high level spinal cord lesion subjects.

ACKNOWLEDGEMENTS

This study was supported by a grant from Cumberland College of Health Sciences.

The authors are grateful to Mr Schelie Nielsen whose technical help was invaluable.

REFERENCES

1. Bar-Or, O., Inbar, O. & Spira, R.: Physiological effects of sport rehabilitation on cerebral palsied and post poliomyelitic adolescents. Med Sci in Sports *8:* 157, 1976.
2. Berg, K.: Remarks on physical training of children with cerebral palsy. Acta Paediatr Scand Suppl. *217:* 106, 1971.
3. Engel, P. & Hildebrandt, G.: Long term studies about orthostatic training after high spinal cord injury. Paraplegia *14:* 159, 1976.
4. Ekblom, B. & Lundberg, Å.: Effect of physical training on adolescents with severe motor handicaps. Acta Paediatr Scand *57:* 17, 1968.
5. Gass, G. C. & Camp, E. M.: Physiological characteristics of trained Australian paraplegic and tetraplegic subjects. Med Sci in Sports. In press.
6. Guttmann, L., Munro, A. F., Robinson, R. & Walsh, J. J.: Effect of tilting on the cardiovascular responses and plasma catecholamine levels in spinal man. Paraplegia *1:* 4, 1963.
7. Heigenhauser, C. F., Fuff, C. L., Miller, B. & Faulkner, J. A.: Cardiovascular response of paraplegics during graded arm ergometry. Med Sci in Sports *8:* 68, 1976.
8. Hjeltnes, N.: Oxygen uptake and cardiac output in graded arm exercise in paraplegics with low level spinal lesions. Scand J Rehab Med *9:* 107, 1977.
9. Hüllemann, K. D., List, M., Matthes, D., Wiese, G. & Zika, D.: Spiroergometric and telemetric investigations during the XXI International Stoke Mandeville Games 1972 in Heidelberg. Paraplegia *13:* 109, 1979.
10. Knutsson, E., Lewenhaupt-Olsson, E. & Thorsen, M.: Physical work capacity and physical conditioning in paraplegic patients. Paraplegia *11:* 205, 1973.
11. Lundberg, A., Ovenfors, C. O. & Saltin, B.: Effects of physical training on school children with cerebral palsy. Acta Paediatr Scand *56:* 182, 1967.
12. Nilsson, S., Staff, P. H. & Pruett, E. D. R.: Physical work capacity and the effect of training on subjects with long standing paraplegia. Scand J Rehab Med *7:* 51, 1975.
13. Pollock, M. L., Miller, H. S., Linnerud, A. C., Langbridge, E., Coleman, E. & Alexander, E.: Arm pedalling as an endurance training regimen for the disabled. Arch Phys Med Rehab *55:* 418. 1974.
14. Pollock, M. L., Ward, A. & Ayres, J.: Cardio-respiratory fitness: Responses to differing intensities and duration of training. Arch Phys Med Rehab *58:* 467, 1977.
15. Voigt, E. D. & Bahn, D.: Metabolism and pulse rate in physically handicapped when propelling a wheel chair up an incline. Scand J Rehab Med *1:* 101, 1969.
16. Wolf, E. & Magora, A.: Orthostatic and ergometric evaluation of cord injured patients. Scand J Rehab Med *8:* 93, 1976.
17. Zwiren, L. D. & Bar-Or, O.: Response to exercise of paraplegics who differ in conditioning level. Med Sci in Sports *7:* 94, 1975.

Key words: Quadraplegia, oxygen consumption, anthropometry, spirometry, exercise

Address for reprints:

G. C. Gass, Ph-D
Department of Biological Sciences
Cumberland College of Health Sciences
P.O. Box 170 Lidcombe, N.S.W. 2141
Australia