Paraplegia 27 (1989) 307–313
0031–1758/89/0027–0307$10.00

Arm Crank versus Wheelchair Treadmill Ergometry to Evaluate the Performance of Paraplegics

T. J. McConnell, PhD,[1] M. A. Horvat, EdD,[2] T. A. Beutel-Horvat, MEd,[2] L. A. Golding, PhD[3]
[1] *College of Health, University of Utah, Salt Lake City, Utah, USA,* [2] *Division of HPERD, University of Georgia, Athens, Georgia, USA,* [3] *School of HPERD, University of Nevada, Las Vegas, Las Vegas, Nevada, USA.*

Summary
The purpose of this investigation was to compare peak performance capabilities of male paraplegics with arm crank and wheelchair ergometry. Eleven male paraplegics (aged 26·0 ± 4·5 years) with spinal lesions at levels ranging from T5 to L4 were assessed during arm cranking and while propelling a wheelchair on a treadmill. Subjects completed both tests in randomised order within a 1 week period with a minimum of 48 hours between tests.

Based on the data analysis, peak $\dot{V}O_2$ *for the treadmill and arm crank were not significantly different while HR values for the treadmill were significantly greater* ($P < 0{\cdot}05$) *when compared to arm crank. A regression analysis indicated that wheelchair treadmill peak* $\dot{V}O_2$ *values can be accurately predicted from arm crank peak* $\dot{V}O_2$ ($r = 0{\cdot}74$).
Key words: *Wheelchair treadmill; Arm cranking; Paraplegics; Peak exercise.*

During the past decade there has been an increased participation by paraplegics in sports and other physical activities. The unique physiological adjustments and adaptations required by paraplegics to perform physical activity suggests that a comprehensive assessment of the physical performance capabilities of this population might be helpful in monitoring and improving performance.

The preferred method for assessing physical performance of paraplegics and other lower limb disabled individuals has been the arm crank ergometer or modified bicycle ergometer. Typically, arm cranking devices such as a Monark Rehab Trainer or modified stationary bicycle have been used to assess physical working capacity of the lower limb disabled by allowing the subjects to perform a cranking motion with their arms.

However, the muscle action of arm cranking is dissimilar to the muscle action involved in propelling a wheelchair. Specificity is a well accepted principle of

Correspondence to: Dr M. Horvat, Division of HPERD, Physical Education Building, University of Georgia, Athens, GA 30602, USA.

Table I Characteristics of subjects

Subject	Level of lesion	Age (years)	Wt (kg)	Years in chair
1	T12	30	72·4	7
2	T5*	22	71·6	5
3	T10	29	76·1	10
4	T8–12*	23	57·5	2
5	T10	29	69·9	9
6	T1–9	19	57·0	1
7	L1	28	73·0	5
8	T12*	26	66·85	3
9	L2	22	83·0	1
10	T12–L1	30	66·6	4
11	L4	34	83·4	13

* Complete lesion.

training and testing, and may be violated when wheelchair-bound individuals are assessed aerobically using an arm cranking protocol. In an effort to address the principle of specificity, various types of stationary wheelchair ergometry (Glaser, Foley, Laubach, Sawka and Suryaprasad, 1979; Glaser, Sawka, Laubach and Suryaprasad, 1979; Glaser, Sawka, Brune and Wilde, 1980) and wheelchair treadmill ergometry (Burkett, Chisum, Cook, Norton, Taylor, Ruppert and Wells, 1987; Crews, Wells, Burkett and McKeeman-Hopkins, 1982; Gass and Camp, 1979, 1984; Wicks, Lymburner, Dinsdale and Jones, 1978), have been used to simulate the movements of propelling a wheelchair.

Stationary wheelchair ergometry may require substantial and expensive equipment mechanisms as well as modifications to the wheelchair. Other testing variations have included the use of a wide treadmill belt (Engle and Hildebrandt, 1973) or a wooden frame (Crews, Wells, Burkett and McKeeman-Hopkins, 1982) as a safety procedure. Additionally, comparisons among the intensity of exercise has varied. Many investigators have used exercise intensities from 0–5% grades on the treadmill that may not be sufficient to adequately assess peak performance of trained paraplegics (Engle and Hildebrandt, 1973; Hildebrandt, Voight, Bahn, Berendes and Kroger, 1970; Voight and Bahn, 1969). Further, investigations that utilise able-bodied subjects in a wheelchair may not be accurate in comparisons with the disabled. The resulting lack of functional ability will directly affect the exercise potential of the subject.

As a result of the unique mechanical problems and safety concerns associated with testing, there has been a lack of standardisation and consistency among physical performance assessments conducted on paraplegics. This lack of consistency has made comparisons difficult. Therefore, the purpose of this investigation was to compare the peak metabolic and heart rate capabilities of male paraplegics on an arm crank ergometer with performance on a treadmill accommodating a wheelchair. A second purpose of the investigation was to determine the accuracy of using arm crank ergometry as a predicator of peak values on the treadmill.

Methods

Eleven male paraplegics with spinal injuries at the fifth thoracic level (T5) and below (see Table I) participated in two testing sessions in which peak responses

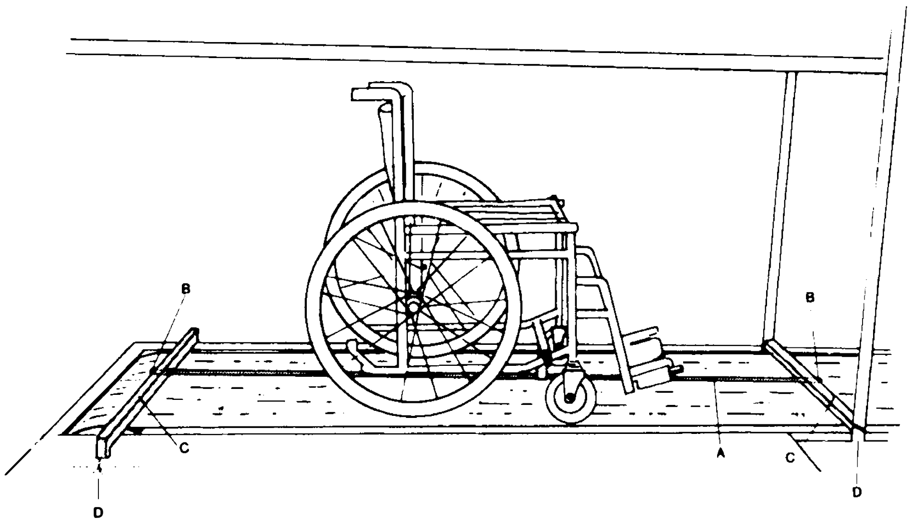

Figure 1 Wheelchair steering mechanism (Reprinted from Horvat *et al.* with permission).

to exercise were assessed while propelling a wheelchair on a treadmill and during arm cranking with an ergometer. Subjects repeated each test in a 2–7 day period. Six randomly assigned subjects completed the treadmill test initially while 5 subjects were tested first on the arm crank.

The arm crank test was conducted on a Monark 880 Rehab Trainer anchored to a laboratory table for stability. A mat was placed under the legs of a desk chair to prevent it from sliding during the test. The arm crank ergometer handles were aligned vertically at shoulder height for each subject and a metronome set at 144 bpm was used to maintain a constant cranking rate.

The resistance for the power output was set at 0 kpm while the subject maintained a cranking rate of 72 rpm. At the end of each 3 minute interval the resistance was increased by 1 kpm with a maximum setting of 4 kpm on the Monark Rehab Trainer. This procedure was adopted from the protocol utilised in a previous investigation (Sawka, Glaser, Wilde and VanLurthe, 1980). In this study, 1 subject exceeded the maximum ergometer setting necessitating an increase in the cranking rate to 80 rpm to increase the power output.

The treadmill test was conducted on a Quinton Model 24-72 clinical research treadmill, which was calibrated at 2 mph with a digital tachometer. An adaptation (Fig. 1) was used to mount the wheelchair on the treadmill consisted of a steering device, a 1·27 cm ($\frac{1}{2}$ in) steel rod attached to the side supports of the treadmill, and suspended approximately 1·27 cm ($\frac{1}{2}$ in) over the treadmill belt (Horvat, Golding, Beutel-Horvat and McConnell, 1984). An aluminium tracking mechanism was clamped between the front wheel frame of a Stainless Medical Products wheelchair and fit over the steering rod allowing the wheelchair to be propelled only forward and backward on the treadmill belt thus allowing no side-to-side movement of the wheelchair. The test wheelchair had a 55·88 cm (22 in) wheelbase and weighed 16 kg (3·52 lbs) while tyre pressure was maintained at approximately 60 psi for each subject.

A progressive intensity protocol was selected to assess maximum performance on the treadmill (Golding, Horvat, Beutel-Horvat and McConnell, 1986). In this protocol, the treadmill belt speed remained constant at 2 mph throughout the test. The initial grade was 0% and was increased by 2% at the end of each 3 minute interval until voluntary maximal exhaustion was reached. The initial two exercise intensities (0 and 2%) served as a warm-up and enough time for adequate adaptation and practice for the subjects.

Identical preparation procedures were utilised for the arm crank and the treadmill test. The procedures consisted of obtaining informed consent, subject preparation, and collection of test data. Peak HR's were measured with a Hewlett-Packard EKG utilising a CM 5 lead, and $\dot{V}O_2$ was determined by a Beckman MMC calibrated with a standard gas previously analysed with a Micro-Scholander gas analyser.

Prior to the initiation of the test, 5 minutes of expired ventilations at quiet rest to assure adequate flushing of the mixing chamber and assuring true mixed alveolar samples was implemented before resting data were collected. During the test, HR and $\dot{V}O_2$ were recorded in the final 30 seconds of each 3 minute interval. Immediately upon completion of the test, recovery HR and $\dot{V}O_2$ readings were recorded.

Data were analysed by a multivariate analysis of variance (MANOVA) to determine if differences existed between peak results of the two test procedures. In addition, unvariate analysis of variance with repeated measures was utilised to compare the group means collected on HR and $\dot{V}O_2$. Finally a simple linear regression was used to predict peak treadmill $\dot{V}O_2$ values from arm crank ergometry peak $\dot{V}O_2$ values.

Results

Based on the MANOVA, no significant differences were apparent in the weighted sums of the dependent variables between the arm crank and wheelchair ergometry tests. The unvariate analysis of variance revealed no significant differences between mean peak $\dot{V}O_2$ $ml \cdot kg^{-1} \cdot min^{-1}$ on the treadmill ($\bar{x}$ = 34·6 ± 9·9) and the arm crank ergometer ($\bar{x}$ = 30·0 ± 7·7). In addition, no significant differences were apparent in $\dot{V}O_2$ $1 \cdot min^{-1}$ for treadmill ($\bar{x}$ = 2·42 ± 0·68) and arm crank ergometry ($\bar{x}$ = 2·15 ± 0·58). The mean peak heart rates indicated a significantly higher heart rate ($F_{1,10} = 5{\cdot}31$, ($p < 0{\cdot}05$) for wheelchair ergometry ($\bar{x}$ = 182 ± 11·1 $bts \cdot min^{-1}$) when compared to the arm crank results ($\bar{x}$ = 171 ± 19·6 · $bts\ min^{-1}$). The regression equation $Y' = 0{\cdot}8554x + 0{\cdot}5788$ predicting treadmill peak $\dot{V}O_2$ $1\ min^{-1}$ from arm crank peak $\dot{V}O_2$ scores resulted in an r of 0·74 with a standard error of prediction ($Sy \cdot x$) of 0·34 $1 \cdot min^{-1}$.

Discussion

The results of this investigation were similar to a previous investigation (Gass and Camp, 1984) in which higher peak although not statistically significant $\dot{V}O_2$ values were reported for wheelchair treadmill ergometry compared to arm crank ergometry. In addition, the $\dot{V}O_2$ reported from the treadmill testing procedures in this investigation were slightly higher than the values reported by Gass and Camp (1984).

In contrast, other investigators reported no difference in peak $\dot{V}O_2$ values. However, a closer observation of each of these studies reveals the use of able-bodied and quadriplegics in the subject groups. For this reason, the reported values may not adequately represent values for paraplegics. Similarly, Wicks *et al.* (1978) reported no variations of peak $\dot{V}O_2$ in the comparison of elite spinal cord injured athletes within their competitive classifications. In addition, Zwiren and Bar-Or (1975) reported values in their investigation for wheelchair athletes comparable to sedentary wheelchair subjects.

Mean peak HR reported on wheelchair ergometry in this investigation support the results reported from other investigations which measured peak HR for upper body work (Crews *et al.*, 1982; Zwiren and Bar-Or, 1975). More precisely, when results from subjects with similar levels of injuries as subjects in this study are compared by group mean HR, the results from this investigation are within one bpm.

Gass and Camp (1984) also reported peak HR on wheelchair treadmill ergometry consistent with this investigation. Other investigations (Wicks *et al.*, 1978; Wicks, Oldridge, Cameron and Jones, 1983) reported no significant difference in the comparison of peak HR for arm crank and wheelchair ergometry. Glaser *et al.* (1979, 1980) also presented results which indicated higher peak HR values on arm crank ergometry when compared to wheelchair ergometry.

Varying differences in peak HR between the treadmill and arm crank tests in this investigation may be attributed to the specificity of wheelchair ergometry as well as the progressive intensity protocol utilised. Since propelling a wheelchair on a treadmill is more specific to the natural movements utilised by paraplegics in daily ambulation and training, it is possible that more muscle mass can be utilised at high workloads eliciting higher HR levels (Voight and Bahn, 1969). In addition, the gradual increase in grade on the treadmill, when compared to the rapid increase in resistance for the arm crank protocol, might have delayed muscle fatigue so that more subjects were able to achieve a more valid estimate of peak HR. Additionally, because of the effect of the environment, diet and/or level of fitness, a number of contributing factors can influence HR.

For this reason, a truer indication of the relationship between tests may be values of $\dot{V}O_2$. The prediction of treadmill values from arm crank ergometry reflects a strong positive correlation between the two testing procedures.

Peak $\dot{V}O_2$ was higher on the treadmill in 8 of 11 subjects (Table II). The explanation for higher values on the treadmill is purely subjective but may be related to the remaining functional ability of these subjects when compared to those with higher injuries and less remaining muscular efficiency.

A subject with a low fitness level might have difficulty maintaining the chair speed or cranking rate necessary to achieve as valid a peak HR or $\dot{V}O_2$ value compared to an individual with a high level of fitness (Wicks *et al.*, 1978). As a result, the peak values recorded on the subjects possessing high levels of fitness are probably closer to the true maximum performance capabilities of the individuals.

Another influence on within group differences may be that since individuals with low level spinal lesions had more muscle mass available, localised muscle fatigue may have been delayed (Taylor, McDonnell and Brassard, 1986). If this is true then an increase in muscle mass available for work would increase oxygen

Table II Individual and group responses of heartrate and oxygen uptake on paraplegics from maximal exercise tests

Subject	Arm crank			Treadmill		
	HR	VO_2		HR	VO_2	
	bts min^{-1}	l min^{-1}	ml kg^{-1}	bts min^{-1}	l min^{-1}	ml kg^{-1}
01	135	1·94	26·8	167	2·52	34·7
02*	187	2·45	34·3	181	2·06	28·8
03	155	1·75	23·0	190	1·85	24·3
04*	187	1·46	24·2	187	1·78	30·9
05	175	3·07	43·2	180	3·31	47·4
06	187	1·47	25·8	187	2·03	35·6
07	187	2·97	40·8	200	2·91	40·2
08*	175	2·46	36·7	187	3·50	54·6
09	138	1·56	18·8	161	2·22	27·1
10	180	1·94	29·2	172	1·43	21·4
11	180	2·57	30·8	185	2·98	35·6
Mean	171	2·15	30·3	182	2·42	34·6
SD	19·6	0·58	7·7	11·1	0·68	9·9

* Complete Lesion.

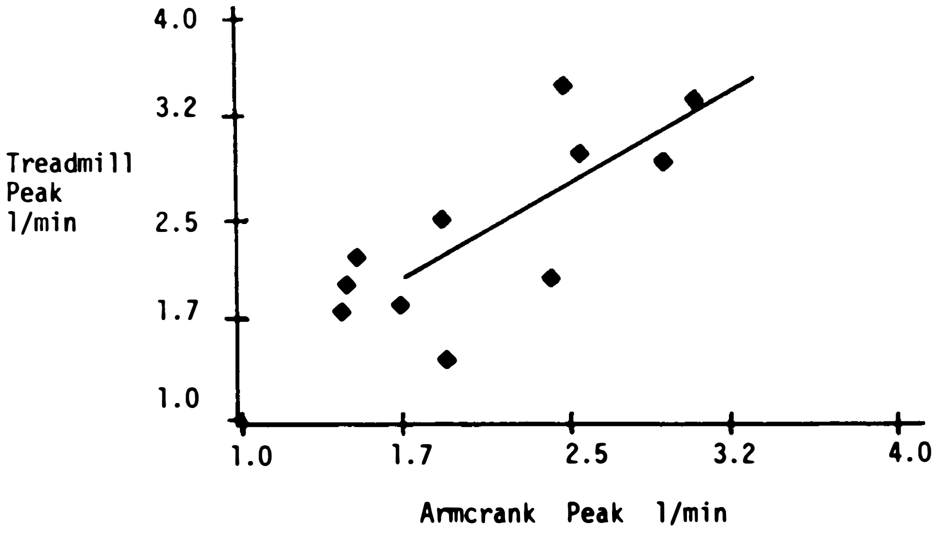

Figure 2 Regression demonstrating the prediction of peak $\dot{V}O_2$ values for treadmill ergometry from peak $\dot{V}O_2$ on Arm Crank ergometry.

uptake. Since arm work generally results in a reduction of $\dot{V}O_2$ by 15–25% the higher the injury the more the individual will be limited in attaining maximal performance values (Cowell, Squires and Raven, 1986).

The assumption that the increase in resistance on the arm crank might induce muscle fatigue before the peak oxygen uptake of the muscle is reached was not apparent in the results of the regression analysis (Fig. 2). Obviously, many factors will contribute to the assessment of paraplegics. The representative accuracy of evaluating these individuals will also vary with the instrumentation available. To compare results may be somewhat misleading as seen by the research conducted by other researchers in different settings and using variable techniques. In spite of the variability of subjects with spinal injuries, research regarding the performance capabilities of this population is closely tied to the assessment methods employed. This calls for more stringent guidelines in methodology and instrumentation before generalising about the population.

In this study, peak $\dot{V}O_2$ values during arm crank and wheelchair ergometry were not statistically different while significantly higher peak heart rates were achieved with wheelchair ergometry. Additionally, a regression analysis of the data revealed a strong relationship between treadmill and arm crank in peak VO_2 values. Peak arm crank or wheelchair VO_2 values may be helpful in predicting maximum capabilities of individuals with various levels of disability. Since the present research demonstrates variability among results in peak heart rates, variables more resistant to external influences such as $\dot{V}O_2$ and instrumentation more specific to the population should be utilised in the assessment of paraplegics.

References

Burkett L, Chisum J, Cook R, *et al.* 1987 Construction and Validation of a Hysteresis Brake Wheelchair Ergometer. *Adapted Physical Activity Quarterly* **4**:60–71.

Cowell LL, Squires WG, Raven PB 1982 Benefits of aerobic exercise for paraplegics: a brief review. *Medicine and Science in Sports and Exercise* **18**(3):501–508.

Crews D, Wells CL, Burkett L, *et al.* 1982 A physiological profile of four wheelchair marathon racers. *Physician and Sportsmedicine* **10**(6):134–143.

Engle P, Hildebrandt G 1973 Long-term spiroergometric studies of paraplegics during the clinical period of rehabilitation. *Paraplegia* **11**:105–110.

Gass GC, Camp EM 1979 Physiological characteristics of trained Australian paraplegic and tetraplegic subjects. *Medical Science in Sports and Exercise* **11**:256–259.

Gass GC, Camp EM 1984 The maximum responses during incremental wheelchair and arm cranking exercise in male paraplegics. *Medical Science in Sports and Exercise* **16**:355–359.

Glaser RM, Foley DM, Laubach LL, *et al.* 1979 An exercise test to evaluate fitness for wheelchair activity. *Paraplegia* **16**:341–349.

Glaser GM, Sawka MN, Laubach LL, *et al.* 1979 Metabolic and cardiopulmonary responses to wheelchair and bicycle ergometry. *Journal of Applied Physiology* **48**(6):1066–1069.

Glaser RM, Sawka MN, Brune MP, *et al.* 1980 Physiological responses to maximal effort wheelchair and arm crank ergometry. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology* **48**:1060–1064.

Golding LA, Horvat MA, Beutel-Horvat T, *et al.* 1986 A graded exercise test protocol for spinal cord injured individuals. *Journal of Cardiopulmonary Rehabilitation* **6**(9):362–267.

Hildebrandt B, Voight ED, Bahn D, *et al.* 1970 Energy costs of propelling a wheelchair at various speeds: Cardiac response and effect on steering accuracy. *Archives of Physical Medicine and Rehabilitation* **51**:131–136.

Horvat MA, Golding LA, Beutel-Horvat TA, *et al.* 1980 A treadmill modification for wheelchairs. *Research Quarterly for Exercise and Sports* **7**:94–98.

Sawka MN, Glaser RM, Wilde SW, *et al.* 1980 Metabolic and circulatory responses to wheelchair and arm crank exercise. *Journal of Applied Physiology* **49**:784–788.

Taylor AW, McDonnell E, Brassard L 1986 The effect of an arm ergometer training program on wheelchair subjects. *Paraplegia* **24** 105–144.

Voigt ED, Bahn D 1969 Metabolism and pulse rate in physically handicapped when propelling a wheelchair up an incline. *Scandinavian Journal of Rehabilitation Medicine* **1**:101–106.

Wicks JR, Lymburner K, Dinsdale SM, *et al.* 1978 The use of multistage exercise testing with wheelchair ergometry and arm cranking in subjects with spinal cord lesions. *Paraplegia* **15**:252-261.

Wicks JR, Oldridge WB, Cameron BJ, *et al.* 1983 Arm cranking and wheelchair ergometry in elite spinal cord injured athletes. *Medical Science in Sports and Exercise* **15**:224–231.

Zwiren LD, Bar-Or 1975 Responses to exercise of paraplegics who differ in conditioning level. *Medical Science in Sports and Exercise* **7**:94–98.