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Effect of chronic use of different propulsion systems in wheelchair design on the aerobic capacity of Indian users

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***Background & objectives*: The use of wheelchairs (WC) of ergonomically different propulsion mechanisms may influence the cardiorespiratory capacity of the WC user. The purpose of the present investigation was to observe the impact of chronic use of four ergonomically different propulsion systems and age of the WC users on their aerobic capacity.**

***Methods*: The male subjects (n=77), exclusively using hand rim (n=20), arm crank using both arms (n=22), arm crank using one arm (n=17), and arm lever using one arm (n=18) propelled WCs and 20 able-bodied (AB) subjects as the control group participated They performed maximal exercise test in continuous, step-wise incremental workload at a crank rate of 50 rpm on an arm-crank ergometer. The VO_2 and heart rate obtained during 2.45 to 3 min of each test exercise, and VO_{2max} and HR_{max} were derived respectively. Two-way ANOVA and multiple comparison tests were performed to compare the groups with respect to VO_{2max} and HR_{max}. Age was used as a classificatory variable.**

***Results*: The maximal physiological response of the AB subjects was superior to the WC users but the WC user groups did not show any significant differences amongst them. The aerobic capacity decreased with advancement of age and for WC users this is more pronounced. Equations for age predicted VO_{2max} and HR_{max} were also derived.**

***Interpretation & conclusion*: As the WC users used the four distinct propulsion systems, it was anticipated that it would induce variation in the physiological variables of the users. But the results of the study revealed that there was no significant difference. Suggesting that the WC users might have developed certain self-regulatory mechanisms in order to overcome the variation induced by the different propulsion systems.**

Key words Aerobic capacity - aging - VO_{2max} - wheelchair users

Most of the wheelchairs (WC) in use in India are based on four propulsion mechanisms- hand rim propulsion (HRP) [1], arm crank propulsion- using both arms (ACP-2)[1] and using one arm (ACP-1)[2], and arm lever propelled using one arm (ALP) [3]. The different propulsion systems require use of different musculature and biomechanics. The cardiovascular fitness of the WC dependant persons decline due to sedentary lifestyle and physiological deconditioning due to illness, prolong WC confinement and limited functional use of skeletal muscle mass placing them at a greater risk of cardiovascular diseases. In order to place such person for WC activities, objective evaluation of the fitness status of the WC dependant

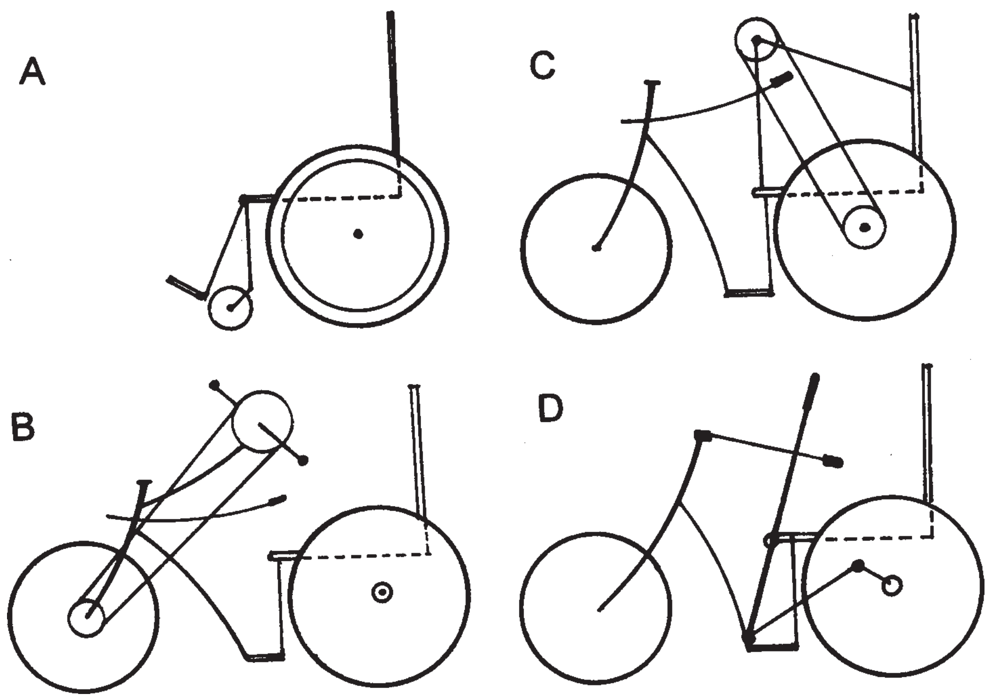

Fig. 1. The wheelchairs of different propulsion systems. A, hand rim; B, arm-crank using both arms; C, arm-crank using one arm; D, arm lever.

individual is necessary. The use of WC of ergonomically different propulsion mechanisms may influence the cardiovascular capacity of the users. Measurement of aerobic capacity or VO_{2max} has been accepted as a most reliable and important index of an individual's cardiorespiratory capacity related fitness status as it indicates the total effort and is a function of total muscle mass involved[4]. Most of the work has been performed on the exercise capacity of individuals with spinal cord injury (SCI) and relationship of maximal oxygen uptake to level of lesion[5], early paraplegia and implications of rehabilitation[6], comparison of arm crank and WC ergometry in spinal cord injured athletes[7], WC dependent individuals[8], protocol selection for upper body exercise[9,10], and effect of endurance training for the disabled[11], paraplegics[12], SCI persons[13]and able-bodied subjects[14]. The aerobic capacity gradually declines with advancement of age[4] and Sawka *et al*[15], also found the same on the disabled males performing WC type activities. Very little information is available on the quantification the aerobic capacity of the users of WC of different propulsion systems and of different ages. We therefore carried out this study to test the impact of chronic use of four different propulsion systems on aerobic capacity of the WC users to determine the influence of age on aerobic capacity of individual confined to a WC; and to observe the difference in aerobic capacity between WC users and able-bodied individuals employing same exercise tests.

Material & Methods

The study was conducted in the Department of Occupational Health, All India Institute of Hygiene and Public Health, Kolkata, during July-October 2000.

Subjects: Male volunteers with a history of paraplegia (below 10th thoracic vertebra) and poliomyelitis, using WCs of four different types of propulsion systems *viz.*, HRP, ACP-2, ACP-1 and ALP participated in the study. All subjects were screened to exclude those with any other symptoms or clinical sign of cardiorespiratory, neurological, orthopaedic or metabolic disorders and WC overuse injury, which could interfere the interpretation. Written consent was obtained from each participant. The study was conducted with a very special group of subjects, the WC users. Moreover, this was a multi-parameter study. Therefore, the rigorous application of statistical

Table I. General characteristics of the participants

Propulsion system	Disability due to	Age (yr)	Height (cm)	Weight (kg)	Years in WC	Duration of use (min)
—	Able-bodied (n=20)	34.55 ±8.78 (19-51)	166.7 ±4.96 (159-176)	52.52 ±3.88 (43.7-61.2)	— — —	— — —
HRP (n=20)	Poliomyelitis (n=7) Paraplegia (n=13)	34.25 ±9.09 (18-51)	153.5 ±6.39 (146-168)	45.00 ±8.76 (34.5-61)	10.15 ±2.41 (7-16)	60.6 ±11.13 (44-77)
ACP-2 (n=22)	Poliomyelitis (n=9) Paraplegia (n=13)	34.64 ±8.83 (18-46)	152.5 ±5.6 (143-165)	43.26 ±6.84 (31.8-56.2)	9.55 ±2.72 (6-17)	124.22 ±38.84 (48-172)
ACP-1 (n=17)	Poliomyelitis (n=5) Paraplegia (n=12)	32.35 ±7.51 (21-44)	155.18 ±6.09 (146-166)	42.78 ±5.93 (32.2-54.8)	8.82 ±2.19 (6-15)	111.70 ±29.64 (62-159)
ALP (n=18)	Poliomyelitis (n=5) Paraplegia (n=13)	32.72 ±8.50 (21-46)	156.22 ±4.57 (150-166)	43.68 ±5.84 (33.2-56.6)	9.94 ±2.51 (6-16)	101.83 ±30.66 (56-151)
WC users (n=77)	Poliomyelitis (n=26)	34.38 ±8.33 (18-51)	153.00 ±5.15 (143-165)	41.78 ±7.00 (31.8-56.6)	10.12 ±2.85 (7-17)	97.42 ±39.96 (44-168)
	Paraplegia (n=51)	33.18 ±8.54 (18-47)	154.84 ±6.04 (146-168)	44.68 ±6.73 (32.2-61)	9.39 ±2.26 (6-15)	100.86 ±37.49 (44-172)

HRP, hand rim propulsion; ACP-2, arm crank propulsion using both arms; ACP-1, arm crank propulsion using one arm; ALP, arm lever propulsion

Values are mean±SD (range)

procedure for finding the sample size was not feasible in this case. All were regular and exclusive users and had been using the respective WC since more than last six years. Three age groups were considered: 18-29, 30-39 and 40-51. Eight subjects were randomly assigned from each age group, from the four propulsive groups. Initially, there were 24 individuals from each propulsive group, 8 from each age group. But all participants could not perform the experiment and finally there were 20, 22,17 and 18 HRP, ACP-2, ACP-1 and ALP users respectively. Twenty sedentary able-bodied (AB) subjects (volunteers) matched as far as possible, the different age groups of WC users served as the control group. Table I shows the physical characteristics of the participants.

The propulsion systems: The criteria of four propulsion systems HRP[1], ACP-2[1], ACP-1[2] and ALP[3] are shown in Table II. Fig.1 shows the WC of different propulsion systems.

Test Protocol: The participants attended several orientation sessions to familiarize with the test procedures, and prior to testing they were explained the purpose of the experiment and extent of their involvement. The exercise was performed on a bicycle

Table II. Criteria of different propulsion systems

Criteria	Wheelchair propulsion systems			
	HRP	ACP-2	ACP-1	ALP
Propulsion mechanism	Hand-rim	Arm-crank	Arm-crank	Arm-lever
Force exerted by	Both arms	Both arms	One arm	One arm
Nature of ride	Short distance, short ride	Long distance, sustained ride	Long distance, sustained ride	Long distance, sustained ride
Mode of propulsion	Synchronous	Asynchronous	—	—
Mode of transportation	Indoor	Outdoor	Outdoor	Outdoor
Efficiency	No	Yes	Yes	Yes
Idling stroke	Yes	No	No	No
Dead point	No	No	No	Yes
Use of back-rest	Less effective	Most effective	More effective	More effective
Required movement	Complex and co-ordinated	Simple and natural	Simple and natural	Simple and natural
Involvement of muscle mass	Lesser than all other systems	Greater than all other systems	> ACP-2, ALP	>ACP-2
Physiological strain	Most strenuous	Lesser than all systems.	<HRP but >ACP-2, ALP	<HRP, ACP-1 but >ACP-2
Speed (m/min)	56.4[1]	134.2[1]	122.79[2]	122.2[3]

HRP, Hand rim propulsion; ACP-2, arm crank propulsion using both arms; ACP-1, arm crank propulsion using one arm; ALP, arm lever propulsion
Superscript numerals denote references

ergometer (Cycle Ergometer, Rodby Electronik AB: RE830, Ergo System, Sweden), braked by electronically controlled generator, modified for arm work. The subjects reported to the laboratory for arm-ergometer testing in two separate sessions. All tests were performed at least two hours after the last meal. The first session involved submaximal testing and their exact placement in relation to pedal crank. In the second session, the subjects underwent a progressive, continuous maximal effort protocol to peak effort (volitional fatigue). The initial workload was 25 watts with increment of 20 watts, every 3 min, and cranking was continued till the subject terminated his work due to exhaustion. The subjects observing an electronic speedometer maintained the crank revolution rate at 50 rpm. During the experiment subjects were verbally encouraged to exert their best effort so that the maximal value was attained. Physiological data were obtained during 2.45 to 3 min of each test exercise 3-min stage. Heart rate (HR) was monitored using Sportstester PE3000 (Polar electro Inc, Finland), - a lightweight telemetric heart rate monitor and oxygen consumption was measured using Oxylog (P.K. Morgan Ltd, England), the portable oxygen consumption meter calibrated before each test. The subjects exercised at increasing intensities and a level of work rate was established beyond which a further increase in work output did not bring about any

Table III. Maximal physiological response at different age groups

Groups	Age group (yr)	Age (yr)	VO_{2max} (ml/kg/min)	HR_{max} (beats/min)
AB	<30 (n=7)	25.42±3.77	33.04±2.59	185.42±6.16
(n=20)	30-39 (n=7)	34.71±2.98	30.48±2.05	184.14±5.45
	≥40 (n=6)	45±4.19	27.41±3.16	174.66±9.37
		34.55±8.78	30.45±3.38	181.75±8.21
HRP	<30 (n=6)	23.5±3.56	24.38±1.77	174.5±2.25
(n=20)	30-39 (n=7)	33.71±2.92	19.85±2.24	170.85±4.37
	≥40 (n=7)	44±3.95	15.62±1.65	166.28±5.31
		34.25±9.09	19.73±4.06	170.35±5.28
ACP-2	<30 (n=6)	22.83±3.92	26.54±1.45	180.66±4.22
(n=22)	30-39 (n=8)	34.75±3.23	24.82±2.03	176.75±6.24
	≥40 (n=8)	43.37±2.06	18.03±2.23	170.87±2.69
		34.64±8.83	22.83±4.21	175.68±5.85
ACP-1	<30 (n=7)	25±2.82	23.65±1.65	176.28±3.94
(n=17)	30-39 (n=6)	34.16±2.63	21.59±2.89	172.33±5.78
	≥40 (n=4)	42.5±1.73	19.37±2.17	166.75±3.86
		32.35±7.51	21.92±2.74	172.65±5.80
ALP	<30 (n=8)	24.37±2.82	23.60±2.55	175.37±4.53
(n=18)	30-39 (n=5)	36.2±3.27	22.60±3.15	174.6±5.17
	≥40 (n=5)	42.6±2.40	18.8±2.01	165.6±1.81
		32.72±8.5	21.99±3.21	172.44±5.89

Values are mean ± SD
AB, Able bodied; HRP, hand rim propulsion; ACP-2, arm crank propulsion using both arms; ACP-1, arm crank propulsion using one arm; ALP, arm lever propulsion

increase in VO_2. This plateauing of VO_2 was considered as the indication that the maximum level has been reached[16].

Environment: All the tests were conducted in a comfortable environment (temperature- dry bulb: 21.6 ± 3.1°C; wet bulb: 17.6 ± 2.9°C, relative humidity 67 ± 8%).

Statistical analysis: In order to test homogeneity of the users of different propulsion systems with respect to some common physical parameters like height, weight, years in WC and duration of daily use, one-way analysis of variance (ANOVA) was done separately for each parameter.

Two-way ANOVA with unequal number of observations per cell was performed to analyze the data on measurement of VO_{2max} and HR_{max}, of each parameter of different group of subjects. The sources of variation were usage of different propulsion systems (along with the control group) and age. The interaction effect was also studied. The subjects were divided into three age groups. Intergroup comparisons of mean

Table IVa. Results of the two-way analysis of variance (ANOVA) for VO_{2max} on WC propulsion mechanism along with control (AB) by age for repeated measurement with unequal number of observations in each group

Factor	Degrees of freedom	Sum of squares	Sum of squares	Factors
WC (adjusted)	4	664.16	1345.47	WC (unadjusted)
Age (unadjusted)	2	703.69	22.38	Age (adjusted)
WC x age	8	748.40	748.40	WC x age
Between cells	14	2116.25	2116.25	Between cells
Within cells(error)	82	427.43	427.43	Within cells(error)
Total	96	2543.68	2543.68	Total

F (WC x age) = 17.96, $P< 0.01$; F (WC) = 12.71, $P< 0.01$; F (age) = 0.85, $P>0.05$

Table 4b. Age group-wise analysis of variance (ANOVA) and pair-wise comparison of mean values of VO_{2max} on WC propulsion mechanism along with control (AB)

Factor	Degree of freedom	Sum of squares	Mean squares	F	Significance
Age (<30 yr):					
Between WC	4	447.37	118.84	23.51	*P*<0.01
Within WC (error)	27	128.44	4.76		
Total	33	575.80			
Age (30-39 yr):					
Between WC	4	464.1	116.02	18.98	*P*<0.01
Within WC (error)	27	164.98	6.11		
Total	33	629.08			
Age (≥40 yr):					
Between WC	4	500.62	125.15	25.21	*P*<0.01
Within WC (error)	27	134	4.96		
Total	33	632.62			

Multiple comparison probabilities (with Bonferroni correction) – at level α=0.05:

Age <30 yr:	HRP	ACP-2	ACP-1	ALP
AB	S (*P*<0.01)	S (*P*<0.01)	S (*P*<0.01)	S(*P*<0.01)
HRP	—	NS	NS	NS
ACP-2		—	NS	NS
ACP-1			—	NS
Age 30-39 yr:	HRP	ACP-2	ACP-1	ALP
AB	S (*P*<0.01)	S (*P*<0.01)	S(*P*<0.01)	S(*P*<0.01)
HRP	—	S(*P*<0.05)	NS	NS
ACP-2		—	NS	NS
ACP-1			—	NS
Age ≥40 yr:	HRP	ACP-2	ACP-1	ALP
AB	S(*P*<0.01)	S(*P*<0.01)	S(*P*<0.01)	S(*P*<0.01)
HRP	—	NS	NS	NS
ACP-2		—	NS	NS
ACP-1			—	NS

AB, Able bodied; HRP, hand rim propulsion; ACP-2, arm crank propulsion using both arms; ACP-1, arm crank propulsion using one arms; ALP, arm lever propulsion; S, significant; NS, not significant

Table Va. Results of the two-way analysis of variance (ANOVA) for HRmax on WC propulsion mechanism along with control (AB) by age for repeated measurement with unequal number of observations in each group

Factor	Degrees of freedom	Sum of squares	Sum of squares	Factors
WC (adjusted)	4	193.96	1556.93	WC (unadjusted)
Age (unadjusted)	2	1448.74	85.78	Age (adjusted)
WC x age	8	1472.43	1472.43	WC x age
Between cells	14	3115.14	3115.14	Between cells
Within cells(error)	82	2101.18	2101.18	Within cells(error)
Total	96	5216.33	5216.33	Total

F(WC X age) = 184.05, $P< 0.01$; F(WC) = 25.62, $P< 0.01$; F(age) = 7.18, $P> 0.05$

Table 5b. Age group-wise analysis of variance (ANOVA) and pair-wise comparison of mean values of HR_{max} on WC propulsion mechanism configuration along with control (AB)

Factor	Degree of freedom	Sum of squares	Mean squares	F	Significance
Age (<30 yr):					
Between WC	4	572.38	143.09	7.15	*P*<0.01
Within WC (error)	29	579.85	19.99		
Total	33	1152.23			
Age (30-39 yr):					
Between WC	4	744.13	186.03	6.48	*P*<0.01
Within WC (error)	28	803.75	6.1128.70		
Total	32	1547.88			
Age (≥40 yr):					
Between WC	4	349.88	87.47	3.05	*P*<0.05
Within WC (error)	25	717.59	28.70		
Total	29	1067.46			

Multiple comparison probabilities (with Bonferroni correction) – at level α*=0.05*:

Age <30 yr:	HRP	ACP-2	ACP-1	ALP
AB	S(*P*<0.01)	NS	S(*P*<0.01)	S(*P*<0.01)
HRP	—	NS	NS	NS
ACP-2		—	NS	NS
ACP-1			—	NS
Age 30-39 yr:	HRP	ACP-2	ACP-1	ALP
AB	S(*P*<0.01)	S(*P*<0.05)	S(*P*<0.01)	S(*P*<0.01)
HRP	—	NS	NS	NS
ACP-2		—	NS	NS
ACP-1			—	NS
Age ≥40 yr:	HRP	ACP-2	ACP-1	ALP
AB	S(*P*<0.05)	NS	S(*P*<0.05)	S(*P*<0.05)
HRP	—	NS	NS	NS
ACP-2		—	NS	NS
ACP-1			—	NS

AB, Able bodied; HRP, hand rim propulsion; ACP-2, arm crank propulsion using both arms; ACP-1, arm crank propulsion using one arm; ALP, arm lever propulsion; S, significant; NS, not significant values were made after using adjustments (Bonferroni correction) for multiple comparisons. All tests were two-tailed and *P*<0.05 was considered statistically significant.

The linear relationships between age and VO_{2max} as well as that between age and HR_{max} were analyzed by using product-moment correlation coefficient (r). Also, the linear models with age as the predictor variable and VO_{2max}/HR_{max} as criterion variable (for each group of subjects) have been developed, along with their coefficient of determination (R^2).

Results

The AB group performed exercise at much higher workload than did the WC users. One way ANOVA showed no significant variation in average values of the test parameters related to physical characteristics among the users of different propulsion systems except duration of use which was significantly less in HRP group.

The test parameters were VO_{2max} and HR_{max} classified by age and propulsion systems are shown in Table III.

Two-way analysis of variance technique with unequal number of observations in cells was applied to find the simultaneous effect of propulsion systems and age on VO_{2max}. The interaction effect (propulsion system x age) and the effect of propulsion systems were found to be statistically significant (*P*<0.01). But the other main effect *i.e.*, age was not significant (*P*>0.05; Table IVa). This suggested the overall change in aerobic capacity due to age, when viewed after confounding the effect of propulsion system, was not much. But following the significance of interaction effect, the effects of different propulsion systems were tested at each level of age. This was done by using one way analysis of variance followed by multiple comparison tests (t-tests at a probability level of α= 0.05/0.01 with Bonferroni correction for multiple comparison). F value for all three age groups were found to be highly significant (*P*<0.01; Table IVb). For the age group <30 yr the control group having a mean VO_{2max} of 33.04 ml/kg/min was significantly higher (*P*<0.01) than HRP (24.38 ml/kg/min), ACP2 (26.54 ml/kg/min), ACP1 (23.65 ml/kg/min) and ALP (23.60 ml/kg/min). Similar results were obtained for the other two age groups suggesting that the able-bodied persons have a significantly higher aerobic capacity than the users of different types of propulsion systems. But differences in average VO_{2max} between the pairs of WC users group, although showed some observed differences, were not statistically significant, except in one case. In the age group (30-39 yr) the mean value of VO_{2max} of ACP-2 group (24.82 ml/kg/min) was found to be significantly higher (*P*<0.05) than HRP group (19.85 ml/kg/min).

Analysis of variance and multiple comparison tests were followed for comparison of the observed values of HR_{max} in different age groups of users of four types of propulsion systems and the control group. The interaction effect of age and propulsion system as well as the main effects of age and propulsion systems were highly significant (*P*<0.01; Table Va). Age group wise analysis of variance and pair-wise comparison of mean values of HR_{max} were done. F-tests were highly significant for all the three age groups, *P*<0.01 for the first two age groups and *P*<0.05 for age groups 40 yr and more (Table Vb). For this parameter (HR_{max}), as observed for VO_{2max}, the control group had a significantly higher mean value as against HRP, ACP-1 and ALP system user groups for all the three age groups, albeit at a lower significance level (*P*<0.05) in some cases (Table III). But the difference was not significant while compared to ACP-2 group in the age groups < 30 and ≥40 yr. For the age group 30-39 yr the difference was significant (*P*<0.05).

Relationship between age and VO_{2max} and age and HR_{max}, for the different experimental groups (WC users) and the control group (AB) was assessed separately. In the regression equations in all cases, ages of the subjects have been used as independent variable and VO_{2max} and HR_{max} are used as dependent variables, as required. The correlation coefficients, their significance level as well as coefficients of determination (R^2) have also been calculated. The relations, as expected are negative everywhere (Table VI; Fig.2).

The HR_{max} was correlated with age predicted HR_{max} (HR_{max}= 220-age[17], corrected –10 beats/min for arm exercise, to be lower than leg exercise)[18]. The correlation coefficient between the two sets of values was 0.63 (*P*<0.001).

Table VI. Relationship of VO_{2max} and HR_{max} with age

	Correlation	r (*P*<)	Regression equation	R^2 value
AB (n=20)	Age vs VO_{2max}	- 0.79 (0.001)	y= - 0.3079x+41.096	0.63
	Age vs HR_{max}	- 0.69 (0.001)	y= - 0.6493x+204.18	0.48
HRP (n=20)	Age vs VO_{2max}	- 0.85 (0.001)	y= - 0.3836x+32.871	0.73
	Age vs HR_{max}	- 0.62 (0.01)	y= - 0.363x+182.8	0.39
ACP2 (n=22)	Age vs VO_{2max}	- 0.85 (0.001)	y= - 0.4093x+37.003	0.73
	Age vs HR_{max}	- 0.72 (0.001)	y= - 0.4847x+192.47	0.53
ACP1 (n=17)	Age vs VO_{2max}	- 0.71 (0.001)	y= - 0.2624x+30.407	0.51
	Age vs HR_{max}	- 0.72 (0.001)	y= - 0.5654x+190.94	0.53
ALP (n=18)	Age vs VO_{2max}	- 0.60 (0.01)	y= - 0.2294x+29.499	0.36
	Age vs HR_{max}	- 0.67 (0.001)	y= - 0.4666x+187.71	0.45
Total WC users (n=77)	Age vs VO_{2max}	- 0.74 (0.001)	y= - 0.3328x+32.802	0.55
	Age vs HR_{max}	- 0.62 (0.001)	y = - 0.4445x+187.8	0.39

AB, Able bodied; HRP, hand rim propulsion; ACP-2, arm crank propulsion using both arms; ACP-1, arm crank propulsion using one arm; ALP, arm lever propulsion

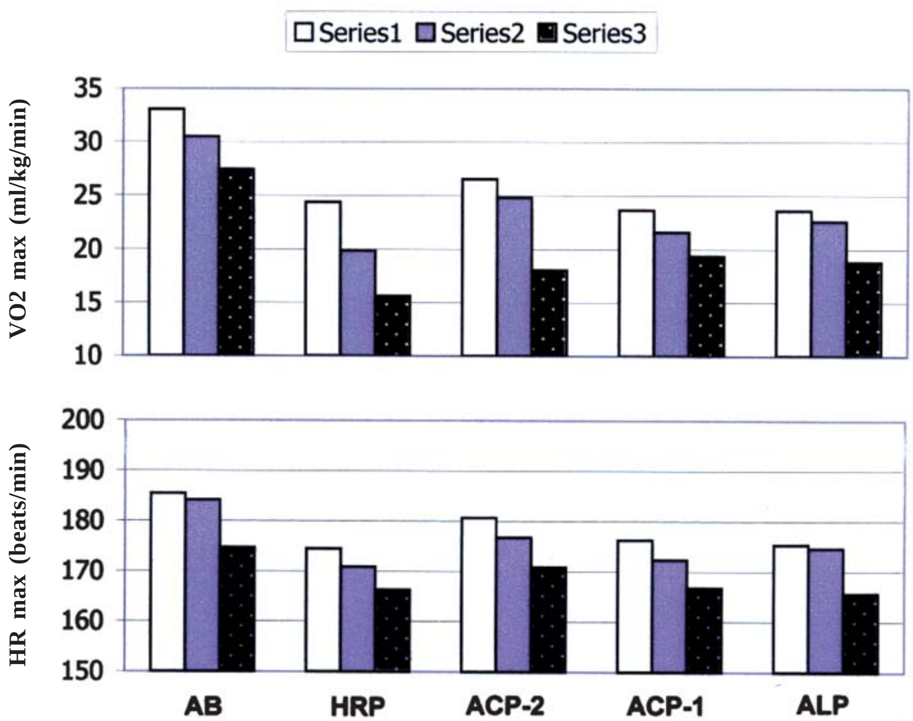

Fig. 2. The effect of age on VO_{2max} and HR_{max}. Series 1, 2 and 3 represent age groups <30, 30-39 and ≥40 yr respectively. AB, Able-bodied; HRP, hand rim propulsion; ACP-2, arm crank propulsion using both arms; ACP-1, arm crank propulsion using one arm; ALP, arm lever propulsion.

Discussion

In the present study the WC users of different propulsion systems were regularly ambulating with the help of WC. Apart from their routine ambulation, none of them was involved in sports activities or special fitness training. This prevented induction of individual differences in physiological conditions of the subjects of different propulsion systems. Cross-sectional sampling limitations prevented any generalization of the results of this study. The age group of 50-60 yr was not considered because of unavailability of subjects, as most of them were not suitable to perform that stressful exercise.

The height and weight of the subjects (AB and disabled) under study were remarkably lower than the subjects of western countries and this might be due to the ethnic difference. The average height and weight of the subjects in the present study were however, consistent to the values of AB and disabled, in an early Indian study[19] and also for the disabled in our earlier studies[1-3].

The arm crank ergometry was chosen in the present study, as it was simple, inexpensive and easily available since it required only a modified bicycle ergometer. Since the users of variety of propulsion systems participated, it was a simplification to put all systems in just one category. Wicks and coworkers[20] reported no difference in maximal cardiorespiratory response in arm cranking and wheelchair exercise whereas Shephard[21] found arm cranking produced higher VO_2 values than WC ergometer. The continuous test design was administered as it was found to be reliable[8,11] and had no significant difference in physiological response at the crank rate of 50 rpm[11]. The validity and reliability have been documented for Oxylog[22] and Sportstester[23]. Consistent subject placement relative to the pedal crank was also taken into consideration to control for inter-subject variability of the elicited responses[9]. As the maximal effort and termination were subjective, the problem arose whether the true peak value was attained. However, the significant correlation between measured HR_{max} and the corresponding values of age predicted HR_{max} corroborated that the subject groups attained maximal oxygen consumption level as the maximal aerobic power was based on attainment of age predicted maximal heart rate[24].

The aerobic capacity of the Indian WC users as well as AB for arm crank ergometry was relatively lower than the western counterpart; this could be due to the poor physique and nutritional status of the subjects. The VO_{2max} of the Indian WC users was lesser than that reported in the western studies[5,6]. The possible reasons might be (*i*) the activities of the WC users, were sedentary in nature and they limited their activities only to the routine ambulation; and (*ii*) their habitual physical activities did not tax the cardiorespiratory and musculoskeletal systems to a sufficient amount in terms of speed and endurance so they were unable to maintain and improve physical fitness to a satisfactory level.

The aerobic capacity of the WC users was significantly lower than that of the AB group. Two reasons could perhaps be attributed to this: (*i*) effect of disease, inactive lifestyle, prolonged WC confinement and the involvement of smaller skeletal muscle mass, due to lack of active stabilization of the body using muscle of lower limbs and trunk during arm exercise; and (*ii*) the maximal work load attained by the WC users during the test was comperatively lower than the AB persons. This suggested that the WC users would have lower maximal cardiac output and oxygen uptake than the AB.

The aerobic capacity of the WC users and AB subjects declined with the advancement of age which is well established[4]. But this decline was more pronounced in the last two decade excepting the HRP users where more decline observed in the early decade. This may be attributed to the decrease in attainable HR_{max} and relative inactivity that decreases the functional range of their oxygen transporting system with advanced ages.

In individual propulsion system age has been found to explain a considerable proportion of variation in aerobic capacities of the users. Although these relationships were of different orders, but all of these were found to be significant. So the predicting equation with age as the predictor variable and VO_{2max} and HR_{max}, respectively as criterion variable may be used to estimate these two physiological parameters of the lower limb disabled, whenever necessary equipment are not available in different rehabilitation set up in India.

No significant variation in the values of VO_{2max} was observed in relation to the difference in propulsion system, in this investigation except for the differences between HRP and ACP-2 in the 30-39 yr age group. The possible cause for this difference might be either due to the advantage of specificity of exercise availed by the ACP-2 group or due to the skill developed by prolong use. However, the routine ambulation (without any fitness training) leads to physiological adaptations in the individual muscular activities to their respective propulsion systems but this is not of sufficient intensity to produce training effect[25], the aerobic capacity was no longer maintained by the same group with advancement of age. As a matter of fact, the influence of habitual physical activities of the users on VO_{2max} seemed not to be statistically significant, as all the users acquired physiological adaptations of their respective propulsion systems during their routine ambulation of their respective WC involving muscular activities.

In conclusion, the AB subjects were found to be superior to their WC user counterpart. The decline in aerobic capacity with advancement of age was seen in both the able-bodied and the WC users, but in WC users it was more pronounced. The WC users used the four distinct ergonomically different propulsion systems. Hence it was anticipated that use of the different configurations would induce different amount of variation in the physiological variables of the users. But, interestingly the results of the study revealed that there was no significant difference in the parameters studied indicating that the WC users might have developed certain self-regulatory mechanisms in order to overcome the variation induced by the different propulsion systems.

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References

1. Mukherjee G, Samanta A. Physiological response to the ambulatory performance of hand rim and arm-crank propulsion systems. *J Rehabil Res Dev* 2001; *38* : 391-9.
2. Mukherjee G, Samanta A. Arm-crank propelled three-wheeled chair: physiological evaluation of the propulsion using one arm and both arm patterns. *Int J Rehabil Res* 2004; *27* : 321-4.
3. Mukherjee G, Samanta A. Energy cost and locomotor performance of low-cost arm-lever-propelled three-wheeled chair. *Int J Rehabil Res* 2001; *24* : 245-9.
4. Astrand PO, Rodahl K. *Textbook of work physiology, physiological basis of exercise*, 3rd ed. New York: McGraw-Hill Book Co.; 1986.
5. Burkett LN, Chisum J, Stone W, Fernhall B. Exercise capacity of untrained spinal cord injured individuals and the relationship of peak oxygen uptake to level of injury. *Paraplegia* 1990; *28* : 512-21.
6. Ellenberg M, MacRitchie M, Franklin B, Johnson S, Wrisley D. Aerobic capacity in early paraplegia: implications for rehabilitation. *Paraplegia* 1989; *27* : 261-8.
7. Wicks JR, Oldridge NB,Cameron BJ, Jones NL. Arm cranking and wheelchair ergometry in elite spinal cord-injured athletes. *Med Sci Sports Exerc* 1983; *15* : 224-31.
8. Glaser RM, Sawka MN, Brune MF, Wilde SW. Physiological responses to maximal effort wheelchair and arm crank ergometry. *J Appl Physiol* 1980; *48* : 1060-4.
9. Sawka MN, Foley ME, Pimental NA, Toner MM, Pandolf KB. Determination of maximal aerobic power during upper-body exercise. *J Appl Physiol* 1983; *54* : 113-7.
10. 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.
11. Pollock ML, Miller HS, Linnerud AC, Laughridge E, Coleman E, Alexander E. Arm pedaling as an endurance training regimen for the disabled. *Arch Phys Med Rehabil* 1974; *55* : 418-24.
12. Bar-Or O, Zwiren LD. Maximal oxygen consumption test during arm exercise - reliability and validity. *J Appl Physiol* 1975; *38* : 424-6.
13. Hooker SP, Wells CL. Effects of low and moderate intensity training in spinal cord-injured persons. *Med Sci Sports Exerc* 1989; *21* : 18-22.
14. van der Woude LH, van Croonenborg JJ, Wolff I, Dallmeijer AJ, Hollander AP. Physical work capacity after 7 wk of wheelchair training: effect of intensity in able-bodied subjects. *Med Sci Sports Exerc* 1999; *31* : 331-41.
15. Sawka MN, Glaser RM, Laubach LL, Al-Samkari O, Suryaprasad AG. Wheelchair exercise performance of the young, middle-aged, and elderly. *J Appl Physiol* 1981; *50* : 824-8.

16. Andersen K, Shephard RJ, Denolin H, Varnauskas E, Masironi R. *Fundamentals of exercise testing*. Geneva: World Health Organization; 1971.

17. American Heart Association, Committee of Exercise: *Exercise testing and training of apparently healthy individuals: A handbook of Physicians*. New York: American Heart Association; 1972.

18. Stenberg J, Astrand PO, Ekblom B, Royce J, Saltin B. Hemodynamic response to work with different muscles groups, sitting and supine. *J Appl Physiol* 1967; *22* : 61-70.

19. Goswami A, Ghosh AK, Ganguli S, Banerjee AK. Aerobic capacity of severely disabled Indians. *Ergonomics* 1984; *27* : 1267-9.

20. Wicks JR, Lymburner K, Dinsdale SM, Jones NL. The use of multistage exercise testing with wheelchair ergometry and arm cranking in subjects with spinal cord lesions. *Paraplegia* 1977; *15* : 252-61.

21. Shephard RJ. Sports medicine and the wheelchair athlete. *Sports Med* 1988; *5* : 226-47.

22. Harrison MH, Brown GA, Belyavin AJ. The “Oxylog”: an evaluation. *Ergonomics* 1982; *25* : 809-20.

23. Janssen TW, van Oers CAJM, van der Woude LHV, Hollander AP. Physical strain in daily life of wheelchair users with spinal cord injuries. *Med Sci Sports Exerc* 1994; *26* : 661-70.

24. McCarthy JP, Agre JC, Graf BK, Pozniak MA, Vailas AC. Compatibility of adaptive responses with combining strength and endurance training. *Med Sci Sports Exerc* 1995; *27* : 429-36.

25. Hildebrandt G, Voight ED, Bahn D, Berendes D, Kroger J. Energy cost of propelling wheelchair at various speeds: cardiac response and effect on steering accuracy. *Arch Phys Med Rehabil* 1970; *51* : 131-6.

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