European Heart Journal (1996) **17**, 1040–1047

Physical responses to different modes of interval exercise in patients with chronic heart failure — application to exercise training

K. Meyer, L. Samek, M. Schwaibold, S. Westbrook, R. Hajric, M. Lehmann*, D. Eßfeldt† and H. Roskamm

*Herz-Zentrum Bad Krozingen, *Universität Ulm, Abt. Sport- und Leistungsmedizin, †Deutsche Sporthochschule Köln, Physiologisches Institut, Germany*

Method In exercise training with chronic heart failure patients, working muscles should be stressed with high intensity stimuli without causing cardiac overstraining. This is possible using interval method exercise. In this study, three interval exercise modes with different ratios of work/recovery phases (30/60 s, 15/60 s and 10/60 s) and different work rates were compared during cycle ergometer exercise in heart failure patients. Work rate for the three interval modes was 50% (30/60 s), 70% (15/60 s) and 80% (10/60 s) of the maximum achieved during a steep ramp test (increments of 25 w/10 s) corresponding to 71, 98 and 111 watts on average. Metabolic and cardiac responses to the three interval exercises were then examined including catecholamine levels and perceived exertion. Parameters measured during interval exercise were compared with an intensity level of 75% peak VO_2, determined during an ordinary ramp exercise test (increments of 12·5 W . min^{-1}).

Results ($\bar{x} \pm SEM$) (1) In all three interval modes, VO_2, ventilation and lactate did not increase significantly during the course of exercise. Mean values during the last work phase were between 754 ± 30 and 803 ± 46 ml . min^{-1} for VO_2, between 26 ± 3 and 28 ± 1 l . min^{-1} for ventilation and between 1·24 ± 0·14 and 1·29 ± 0·10 mmol . l^{-1} for lactate. (2) In mode 10/60 s, heart rate and systolic blood pressure increased significantly (82 ± 4→85 ± 4 beats . min^{-1}; 124 ± 5→134 ± 5 mmHg; $P<0{\cdot}05$ each), while in mode 15/60 s catecholamines increased significantly (norepinephrine 0·804 ± 0·089→1·135 ± 0·094 nmol . l^{-1}; $P<0{\cdot}008$; epinephrine 0·136 ± 0·012→0·193 ± 0·019 nmol . l^{-1}; $P<0{\cdot}005$). (3) In all three modes, rating of leg fatigue and dyspnoea increased significantly during exercise but remained within the range of values considered 'very light to fairly light' on the Borg scale. (4) Compared to an intensity level of 75% peak VO_2, work rate during interval work phases was between 143 and 221%, while cardiac stress (rate–pressure product) was significantly lower (83–88%).

Conclusion All three interval modes resulted in physical response in an acceptable range of values, and thus can be recommended.

(Eur Heart J 1996; 17: 1040–1047)

Key Words: Chronic heart failure, interval exercise, cardiopulmonary exercise testing.

Introduction

In chronic heart failure skeletal muscles show changes in structure[1,2] and metabolic activity[3,4], loss of mass[5], and a reduction of peripheral blood flow due to reduced cardiac output and impairment of flow-dependent ability of arteries to dilate[6–8], which thus reduces exercise capacity. These maladaptations caused increased cardiocirculatory stress which results in a vicious cycle. Goals of exercise training in patients with chronic heart failure are to reverse these maladaptations and to improve the ability to cope with daily living.

In daily life, most physical activities are of an intermittent type (e.g. climbing stairs, hurrying short distances for the bus), and demand both endurance capacity and muscle strength. As many studies affirm that the intensity of exercise training has a more pronounced effect on a subject's exercise capacity than the duration of exercise[9–11], interval exercise training seems

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Revision submitted 30 October 1995, and accepted 13 November 1995.

This work is based on a presentation given at the Joint Workshop 'The Role of Exercise Training and Exercise Testing in Patients with Severe Left Ventricular Dysfunction', sponsored by the Working Group on Exercise Physiology, Physiopathology and Electrocardiography/Working Group on Cardiac Rehabilitation of the ESC in Breisach, Germany, 1–2 June 1995.

Correspondence: K. Meyer, Herz-Zentrum, 79189 Bad Krozingen, Germany.

0195-668X/96/071040+08 $18.00/0

to be an appropriate method to stimulate both endurance capacity and muscle strength. In rehabilitation after bypass surgery, interval training has proven to be more effective in improving exercise capacity and decreasing heart rate, rate–pressure product and lactate at submaximal work rates than continuous training with the same relative training heart rate[12]. Clinical experience with chronic heart failure patients also confirms the benefit of exercise training using interval methods[13,14].

In this study, three interval modes with different work rates were compared during bicycle ergometer exercise in patients with chronic heart failure. The intention was to look for changes in metabolic and cardiac parameters, catecholamine levels, and perceived exertion to different modes of interval exercise.

As interval exercise involves short-work phases with high-work rates, patients' maximum exercise capacity over a short time period was determined by a special test, the steep ramp test, in order to derive intensity levels for interval exercise. For practical interest and safety reasons the metabolic and cardiac parameters, catecholamine levels and rate of perceived exertion during interval exercises were compared with a submaximum intensity level of 75% of peak VO_2 derived from an ordinary ramp exercise test.

Methods

Patients

Sixteen male patients (aged 54 ± 9 years; height 178 ± 5 cm; weight 80 ± 8 kg) with chronic heart failure due to dilated cardiomyopathy (n=10) and coronary heart disease (n=6) were assessed. Four patients were in NYHA class II and 12 patients in class III. Central haemodynamics were severely impaired with a mean ejection fraction of 29 ± 10% at rest, a mean maximum diastolic pulmonary artery pressure of 36 ± 10 mmHg and a mean maximum cardiac output of 8·2 ± 3·4 l . min^{-1}. Maximum aerobic capacity was also markedly impaired with a VO_2 of 1163 ± 289 ml . min^{-1} or 14·5 ± 0·9 ml . kg . min^{-1} on average. All patients were clinically stable for at least 6 weeks. None displayed signs and symptoms of acute myocardial ischaemia or peripheral artery disease. None had a pacemaker and all were in sinus rhythm. Lung function was normal. All patients were on ACE inhibitors and diuretics, ten on nitrates, six on beta-blockers and three on digitalis. This study was approved by the Ethical Committee of the sponsoring institution. Informed consent was obtained from all patients.

Exercise testing procedures

Patients continued to take routine medication before exercise testing. A steep ramp test on a bicycle ergometer was carried out as follows: after 3 min of pedalling unloaded, work rate was increased by 25 W every 10 s. The test was stopped when patients could not maintain 60 revolutions . min^{-1}. The achieved maximum work rate (watt) was called 'maximum short-time exercise capacity' (MSEC).

Three different interval exercise tests (one per day) were carried out in randomized order: mode (a), work phases of 30 s using an exercise intensity of 50% of MSEC; mode (b), work phases of 15 s using an exercise intensity of 70% of MSEC; mode (c), work phases of 10 s using an exercise intensity of 80% of MSEC.

During the first work phases, work rate was successively increased (Fig. 1) to reach the final work rate at measurement points 6 (modes (a) and (b)) and 8 (mode (c)). In all modes recovery phase lasted 60 s while patients pedalled with 15 W.

For the three interval tests the measured parameters were analysed separately for the work and recovery phases. Data are presented for the first measurement point with the definitive work rate (i.e. measurement point 6 for mode (a) and (b), and 8 for mode (c); see Fig. 1) and the following recovery phases (i.e. measurement point 7 for modes (a) and (b) and 9 for mode (c); see Fig. 1) as well as for the last work phases (measurement points 16, 22, 26) and recovery phases (measurement points 17, 23, 27).

An intensity level of 50% MSEC was applied because of the beneficial effects shown in previous training studies[13,14]. To assess if the patients can tolerate higher work intensities if duration of work phases are shortened, 70% of MSEC (mode (b)) and 80% (mode (c)) were chosen. To ensure that the total amount of work performed in each mode was equal, the number of work phases and thus the total exercise time were adjusted (Fig. 1, Table 1). Furthermore, ramp bicycle ergometry (12·5 W . min^{-1}) was carried out to determine the intensity level 75% of peak VO_2.

Measured variables

Heart rate was recorded continuously on a 12-lead electrocardiogram, and blood pressure by plethysmomanometry (Finapres). Using an Oxycon sigma system (Mijnhard), oxygen uptake (VO_2; ml . min^{-1}), carbon dioxide production (VCO_2; ml . min^{-1}) and ventilation (VE; l min^{-1}) were measured breath by breath and averaged over 10 s. Using capillary blood obtained from earlobes, lactate was enzymatically determined and norepinephrine and epinephrine levels were radioenzymatically determined. Ratings of perceived exertion (leg fatigue and dyspnoea) were determined by means of a Borg scale with ratings from 6 to 20[15].

Acid–base status (H^+ ion concentration, nmol . l^{-1}; standard bicarbonate, mmol . l^{-1}; base excess, mmol . l^{-1}) was determined at rest, at measurement points 6 (modes (a) and (b)) and 8 (mode (c)) and in the last work phase of the three interval modes (see Fig. 1).

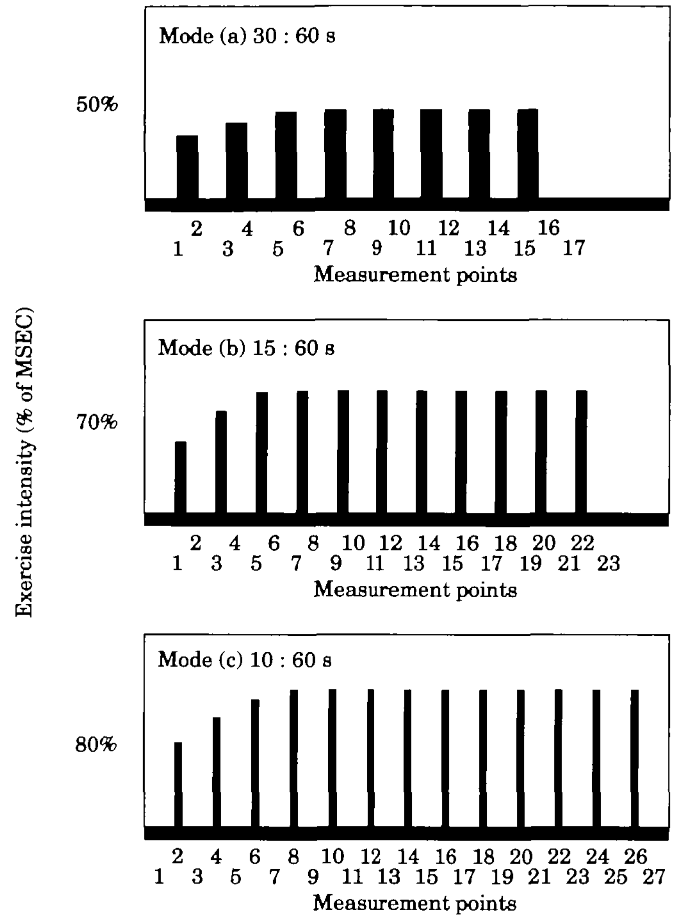

Figure 1 **Interval exercise using three different modes. (50, 70 and 80% indicates the relative exercise intensity derived from the maximum short time exercise capacity [MSEC] of the steep ramp test.)**

Table 1 ***Characteristics of the three modes of interval exercise assessed***

Interval mode (work/recovery; s)		30/60	15/60	10/60	P<
Work rate (work phase)					
in % of MSEC	x̄	50	70	80	—
Work rate (work phase)	x̄	71	98	111	0·0001
(W)	SEM	4	6	6	
Work rate (work phase)	x̄	0·90	1·23	1·40	0·0001
(W . kg^{-1})	SEM	0·06	0·07	0·08	
Total test duration (min)	x̄	13:00	14:45	16:10	—
Total work	x̄	24 131	24 353	24 575	ns
(W . s)	SEM	803	821	783	

MSEC=maximum short time exercise capacity; W . kg^{-1}=watt per kilogram body weight

Statistics

Data are presented as mean and standard error of the mean (x̄; SEM). To calculate differences between two measured points within one interval mode, Wilcoxon test for paired samples was applied. Differences between the three interval modes were calculated by analysis of variance. A P value of <0·05 was considered significant.

Results

During the steep ramp test, the mean maximum work rate was 140 ± 7 W (test duration 56 ± 3 s), with mean values

Table 2 Changes of parameters at work phases and recovery phases during three modes of interval exercise

Interval mode		30/60 s						15/60 s						10/60 s					
		Work			Recovery			Work			Recovery			Work			Recovery		
Measurement point		6	16	*P*<	7	17	*P*<	6	22	*P*<	7	23	*P*<	8	26	*P*<	9	27	*P*<
VO$_2$	x̄	761	754	—	764	755	—	768	766	—	788	796	—	768	797	—	739	803	—
(ml . min^{-1})	SEM	28	30		25	32		31	38		37	34		33	43		51	46	
VCO$_2$	x̄	677	686	—	686	692	—	666	688	—	698	722	—	694	707	—	668	718	—
(ml . min^{-1})	SEM	29	27		27	32		29	40		35	32		35	46		49	37	
VE	x̄	26	26	—	26	27	—	26	27	—	27	29	0·03	26	28	—	25	28	—
(ml . min^{-1})	SEM	4	3		3	3		4	5		4	4		4	1		8	6	
HR	x̄	84	85	—	82	82	—	83	86	—	80	82	—	82	85	0·05	78	82	0·05
(beats . min^{-1})	SEM	4	4		4	4		4	4		4	5		4	4		4	4	
SBP	x̄	131	129	—	126	122	—	134	134	—	132	125	—	124	134	0·05	127	136	0·006
(mmHg)	SEM	8	6		7	6		7	6		6	6		5	5		4	5	
Lactate	x̄	1·28	1·29	—	1·15	1·29	0·001	1·10	1·24	—	1·41	1·21	—	1·16	1·27	—	1·16	1·21	—
(mmol . l^{-1})	SEM	0·12	0·10		0·11	0·11		0·09	0·14		0·10	0·15		0·1	0·13		0·10	0·12	
NOR	x̄	6·449	5·679	—	5·959	5·115	0·02	4·743	6·696	0·008	4·920	5·852	—	5·458	6·213	—	4 962	5·180	—
(nmol . l^{-1})	SEM	0·530	0·502		0·531	0·454		0·525	0·555		0·502	0·590		0·566	0·584		0·443	0·454	
E	x̄	0·945	0·868	—	1·141	0·688	—	0·743	1·053	0·005	0·732	0·966	0 03	0·895	0·950	—	0·814	0·786	—
(nmol . l^{-1})	SEM	0·076	0·104		0·333	0·049		0·066	0·104		0·055	0·120		0·076	0·082		0·060	0·055	
Leg fatigue	x̄	10·6	11·2	0·02	10·5	10·2	—	10·9	11·9	0·007	9·3	10·5	0·004	11·3	12 4	0·001	10·5	10·9	—
	SEM	0·5	0·5		0·5	0·5		0·6	0·5		0·4	0·4		0·4	0·5		0·4	0·4	
Dyspnoea	x̄	10·4	11·0	0·02	9·9	10·3	—	10·3	11·7	0·006	9·3	10·5	0·003	11·0	11·9	0·006	10·1	10·9	0·005
	SEM	0·4	0·5		0·5	0·5		0·5	0·5		0·4	0·4		0·4	0·4		0·4	0·4	

VO$_2$=oxygen uptake; VCO$_2$=carbon dioxide production; VE=ventilation; HR=heart rate, SBD=systolic blood pressure; NOR=norepinephrine; E=epinephrine.

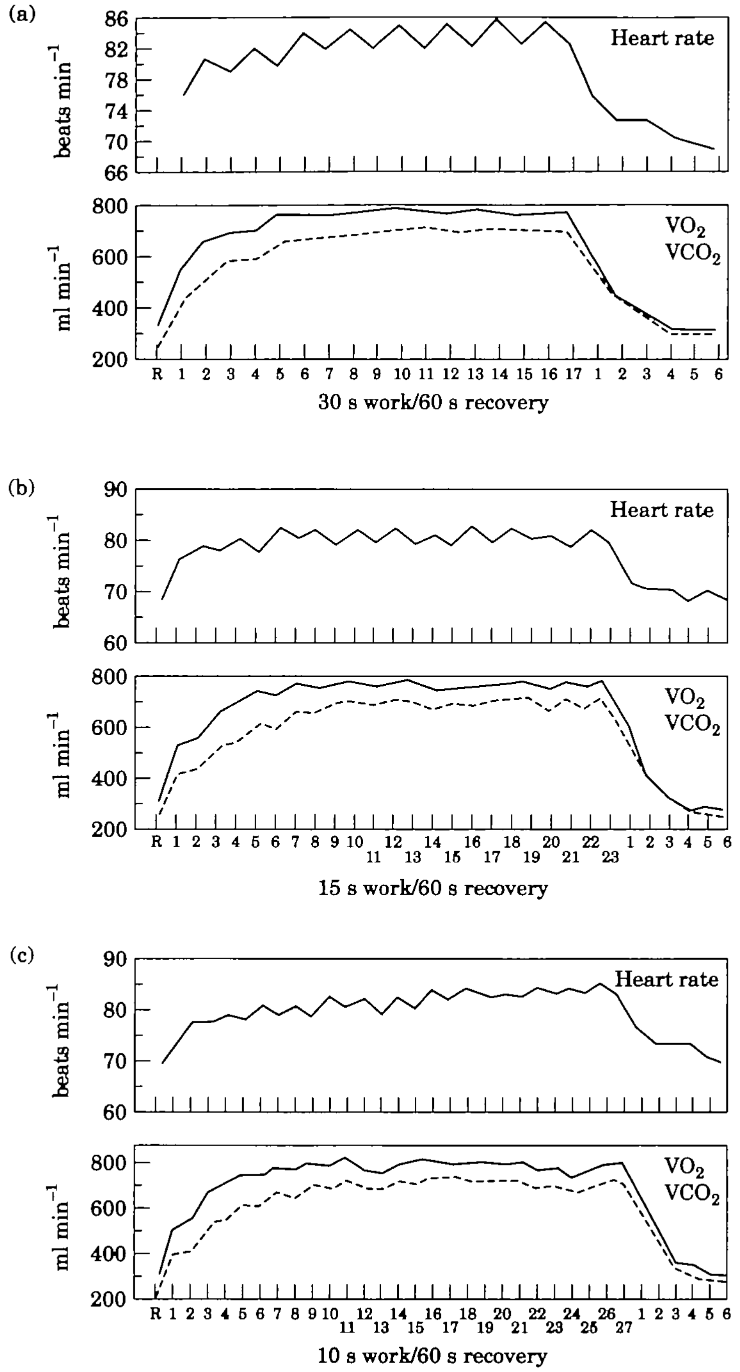

Figure 2 **Responses of heart rate, VO$_2$ and VCO$_2$ during course of interval exercise using three different modes. (Numbers on x-axis are measurement points.)**

for VO$_2$ of 795 ± 49 ml . min^{-1}, heart rate of 96 ± 5 beats . min^{-1} (initial rate 76 ± 5 beats . min^{-1}) and blood pressure of 158/95 ± 10/3 mmHg. Exercise intensity during the three interval modes is presented in Table 1.

In interval mode 30/60 s (see Table 2; Fig. 2(a)), with the exception of ratings of perceived exertion, none of the assessed parameters increased significantly between work phases (measurement points 6 and 16). Between recovery phases (measurement points 7 and 17) only lactate and norepinephrine increased significantly.

In interval mode 15/60 s (Table 2), catecholamines and ratings of perceived exertion increased significantly between both work phases (measurement points 6 and 22) and recovery phases (measurement points 7 and 23). Ventilation was found to be increased solely between recovery phases.

***Table 3** H^+ ion concentration (nmol . l^{-1}), standard bicarbonate (HCO_3^-; mmol . l^{-1}) and base excess (BE; mmol . l^{-1}) at rest and at measurement point 8 (mode (a)), 8 (mode (b)) and 6 (mode (c)) (I) as well as at 16 (mode (a)), 22 (mode (b)) and 26 (mode (c)) (II) (see Fig. 1)*

Interval mode		30/60 s			15/60 s			10/60 s		
Measurement point		H^+	HCO_3^-	BE	H^+	HCO_3^-	BE	H^+	HCO_3^-	BE
Rest	$\bar{x}$	36·121	25·7	1·92	35·529	25·6	1·55	36·336	25·6	1·76
	SEM	0·457	0·7	0·62	0·388	0·70	0·6	0·302	0·47	0·27
I	$\bar{x}$	36·957	24·9	1·29	37·607	25·3	1·29	36·807	24·9	0·91
	SEM	0·251	0·8	0·54	0·305	0·70	0·6	0·603	0·54	0·47
II	$\bar{x}$	36·757	24·9	1·01	36 750	24·5	0·52	37·079	24·5	0·35
	SEM	0·251	0·7	0·62	0·250	0·80	0·08	0·446	0·60	0·46
I vs II $P<$		ns	ns	ns	0 02	0·05	ns	ns	ns	0·02

***Table 4** Work rate and combination of variables for metabolic and cardiac stress, catecholamines and rate of perceived exertion from interval exercise (last work phase) compared to those at an intensity level '75% peak VO_2'*

Interval mode compared to 75% peak VO_2		30/60 s %	15/60 s %	10/60 s %	$P<$
Work rate	$\bar{x}$	143†	196†	221‡	0·0001
	SEM	13	16	16	
Cardiac stress	$\bar{x}$	84†	88*	86*	ns
(Rate–pressure product)	SEM	4	5	5	
Metabolic stress	$\bar{x}$	90*	92	91*	ns
(VO_2, VCO_2, LA)	SEM	4	5	4	
Catecholamines	$\bar{x}$	113	126‡	112	ns
(NOR, E)	SEM	12	11	8	
Rate of perceived exertion	$\bar{x}$	88†	94	97	0·0001
(leg fatigue, dyspnoea)	SEM	3	4	4	

Presented data are percentages.
Significance level P of comparison of interval exercise vs 75% peak VO_2: *0·05; †0·01; ‡0·001.
Only those variables were combined which did not differ significantly in their percentage value.
Abbreviations see Table 2.

In interval mode 10/60 s (Table 2; Fig. 2(c)), between both work phases (measurement points 8 and 26) and recovery phases (measurement points 9 and 27), heart rate, blood pressure and ratings of perceived exertion increased significantly.

For all three interval modes, VO_2 did not differ significantly between work and recovery phases (Table 2; Fig. 2). During the last work phase, significant differences were found for norepinephrine ($P<0·01$), epinephrine ($P<0·02$) and ratings of leg fatigue ($P<0·004$) between the three interval modes. None of the other variables differed significantly. Single parameters from the acid–base status changed slightly but significantly during exercise for interval modes 15/60 s and 10/60 s (Table 3). The parameters did not differ significantly between the three modes.

During the ordinary ramp exercise test, the exercise intensity level of 75% peak VO_2 was accompanied by the following data: work rate 53 ± 5 W; VO_2 873 ± 54 ml . min^{-1}; VCO_2 803 ± 44 ml . min^{-1}; heart rate 93 ± 5 beats . min^{-1}; blood pressure 145/80 ± 6/3 mmHg; norepinephrine 4·970 ± 0·384 nmol . l^{-1}; epinephrine 0·977 ± 0·120 nmol . l^{-1}; leg fatigue as well as dyspnoea 11·2 ± 0·6 on Borg scale.

When comparing data measured during the last work phase of interval exercise to that measured at 75% of peak VO_2, work rate during all three interval modes was significantly higher by 43–121% on average, while cardiac stress was significantly lower by 12–17% on average (Table 4). The metabolic stress was significantly lower in modes 30/60 s (Fig. 1) and 10/60 s, but catecholamines were higher in mode 15/60 s. Ratings of perceived exertion were significantly different only in mode 30/60 s. With the exception of ratings of perceived exertion, no combination of variables differed between the three interval modes (Table 4).

Discussion

As patients with chronic heart failure are characterized during exercise by a rapid decline of phosphocreatine, reduced aerobic capacity, and decreased muscle strength[4,16,17], interval exercise could help overcome the premature muscle fatigue seen during high work rate training and help prepare patients for coping with activities of daily living. This study assessed chronic heart failure patients' toleration for high intensity interval exercise.

Although work rates differed between the three interval modes (Table 1), metabolic stress did not increase significantly during the first and last work phase in all three models, and blood lactate displayed no appreciable lactacid strain (Table 2). Obviously phosphocreatine was sufficient to meet the major part of energy requirement in all interval tests. Similar findings have been reported for interval tests in healthy subjects when the duration of the work phases was below 30 s[18,19]. Although in this study, single parameters of acid–base status changed significantly during mode 15/60 s and 10/60 s (Table 3), the absolute values did not reveal an essential buffering activity. If there had been a low amount of lactate production during these two modes, it had been eliminated during the recovery and/or work phases and could not be detected. Thus, from the metabolic point of view, all three interval modes indicated aerobic exercise and can be recommended.

For all three interval modes, there were no significant differences in VO_2 between work and recovery phases (Table 2; Fig. 2). The mean values of VO_2 were lower relative to intensity in work phases and higher relative to intensity in recovery phases.

In interval mode 30/60 s and 15/60 s, heart rate and systolic blood pressure stabilized during the entire exercise test (Table 2; Fig. 2(a and b)), as is characteristic for aerobic exercise by continuous method. Concerning the cardiac stress in mode 10/60 s, the higher work rate could not be compensated for by the shorter work phases (Table 2; Fig. 2(c)). Nevertheless, the absolute values indicated a cardiac stress which patients could tolerate.

Plasma norepinephrine and epinephrine levels stabilized during interval modes 30/60 s and 10/60 s, as was seen in aerobic training by continuous method in coronary patients when compared to interval training[12]. Furthermore, in all three modes, values were markedly lower compared with those observed in that study. Although catecholamines differed at the end of the three interval exercises, the low values did not indicate that the sympathetic response has an essential share in cardiocirculatory adaptation to exercise[20,21]. Thus, the withdrawal of vagal tone seems to be the primary factor for exercise adaptation[22]. This is another indication that all three interval modes clearly represent aerobic exercise.

The only parameters which increased significantly during the course of exercise were mean ratings of leg fatigue and dyspnoea, but all remained within the range of values considered 'very light to fairly light' on the Borg scale (Table 2). Although the total amount of work was comparable for the three interval exercises, during the last work phase leg fatigue was significantly higher in mode 10/60 s compared with modes 30/60 s and 15/60 s (Table 2). This reflects the higher work stimulus and demonstrates that local factors dominate the sensation of effort during exercise[23,24].

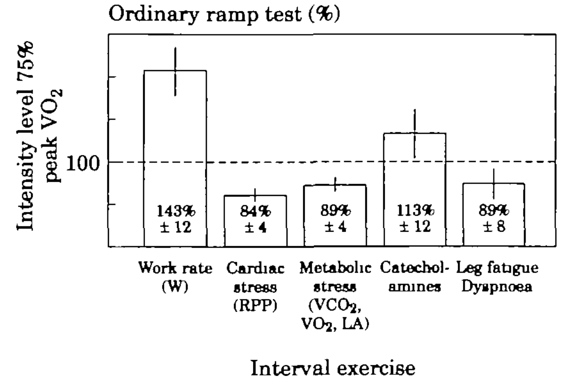

Figure 3 **Work rate and exercise parameters of interval mode 30 s work/60 s recovery phases in % of an intensity level of 75% peak VO_2 (data taken from Table 4).**

Usually, exercise training is prescribed at an intensity level of 75% peak VO_2 achieved during a graded exercise test[25]. In the present study, work rate during the work phases of interval exercise was between 143 and 221% of that work rate which the patients achieved at an intensity level of 75% peak VO_2 during an ordinary ramp test (Table 1). During this interval intensity, values of metabolic stress were lower than those measured at 75% peak VO_2, while catecholamines and ratings of perceived exertion varied (Table 4). It is remarkable to note (see Fig. 3; Table 4) that much higher work rates with lower cardiac stress were achieved during interval exercise than during ramp bicycle exercise at 75% peak VO_2. Thus, exercise guidelines based on an intensity level of 75% peak VO_2 underestimate the intensity which patients could tolerate during interval exercise. As interval exercise involves high work rates over short periods, the steep ramp test was developed to determine the capacity which patients can perform over a short time.

In summary, by a steep ramp test the intensity for interval exercise can be ascertained more appropriately than by an ordinary ramp test. Interval exercise allows greater stimuli which patients probably would not have tolerated if the same intensity had been applied using a continuous method. The importance of the duration of work phases, as well as of the recovery phase, was indicated by a decrease and/or lack of increase of the measured parameters in the course of exercise. This was especially shown by ratings of perceived exertion, indicating subjective tolerance of high work rates.

Essential differences between the three interval modes assessed were not found. Thus, all modes can be recommended, with enough leeway for individual application. With respect to the chosen testing procedure, even higher work rates are conceivable, with prolonged recovery phases if necessary.

We are grateful to Ms Uta Spöri, Medizinische Universitätsklinik Freiburg, for determination of the catecholamine levels.

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