RESPONSES TO ARM AND LEG ERGOMETRY

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ABSTRACT

Arm (A), leg (L) and combined arm and leg (A + L) ergometry modes were compared at power outputs of 49, 73.5 and 98 W. Selected cardiorespiratory variables and a rating of perceived exertion (RPE) were measured for 19 males of mean age 25.7 (± 5.5) years. Oxygen uptake ($\dot{V}O_2$), heart rate (HR), minute ventilation and rating of perceived exertion (RPE) were all higher ($p < 0.01$) in A compared with L and A + L. Gross mechanical efficiency was significantly lower in A ($p < 0.01$) than in L or A + L. No differences were observed in any measurements between L and A + L. The correlations between RPE and cardiorespiratory variables were higher for A (RPE: $\dot{V}O_2$, $r = 0.87$, $p < 0.01$; RPE:HR, $r = 0.78$, $p < 0.01$) than for L and A + L.

Key words: Arm ergometry, Leg ergometry, Air-braked ergometer, Perception of exertion.

INTRODUCTION

The physiological responses to arm exercise have received recent attention in the literature (Franklin et al, 1983; Franklin, 1985; Hagan et al, 1983; Mangum, 1984; Pandolf et al, 1984; Sawka et al, 1982; Vander et al, 1984). This is because arm work as an alternative method of exercise testing and training is justified for specific subjects such as paraplegics, patients with orthopaedic limitations, patients with circulatory problems in the legs (intermittent claudication), patients who suffer cardiac discomfort or who exhibit symptoms of myocardial ischaemia during sustained arm work, and those for whom arm work is a predominant feature in their physical activity (Franklin et al, 1983). In these subjects, upper extremity evaluation or conditioning is particularly appropriate.

The purpose of this investigation was to compare specific circulatory and respiratory responses, RPE and gross mechanical efficiency in young men using a combined arm and leg air-braked ergometer during low to moderate levels of power output.

METHODS

Nineteen healthy students or employees of the University of Liverpool volunteered to participate in this study (age 27.7 ± 5.5 yr, weight 73.9 ± 4.6 kg, height 178.2 ± 6.0 cm). All subjects gave informed consent to the experiment. No subject possessed any known pathological condition and all were physically active.

Each subject performed at workrates of 49 W, 73.5 W and 98 W for four minutes on a Schwinn Air-Dyne ergometer in each of three exercise modes. The Air-Dyne ergometer is a stationary cycle that utilises the resistance of air on wind vanes set perpendicular to the flywheel. The resistance and thus the workload is proportional to the angular velocity of the perimeter of the wind vane flywheel. Power output is produced by foot pedals and arm levers that are connected to the flywheel by a common drive shaft. Thus, both the foot pedals and arm levers move together when one or the other is in operation. During combined arm and leg work, it is not possible to differentiate the power output of the arms from that of the legs.

The three work tests on the ergometer were presented to each subject in random order and involved arm work (A), leg work (L) and combined arm and leg work (A + L). Subjects remained seated at all times.

Respiratory variables, including oxygen uptake ($\dot{V}O_2$), minute ventilation (VE) and respiratory exchange ratio (R) were measured continuously using an Oxycon 4 ergoanalyser (Mijnhardt). Expired air was directed through a speak-easy II low resistance valve (Vacuumed), which

allows verbal communication with the subject during exercise testing. Exercise heart rates (HR) were measured using a Lifetrace 12 cardiometer (Albury Instruments). RPE was subjectively rated with the Borg 6-20 scale (Borg, 1970) in the last 15 seconds of each workload.

Gross mechanical efficiency (E%) was calculated as the ratio of power output to metabolic energy input. Metabolic energy input was calculated from the caloric values for non protein R per volume of oxygen consumed and converted to equivalent power output units as described by Fox and Mathews (1981).

The data were analysed by a one factor analysis of variance (ANOVA) at each exercise intensity. The Scheffé post-hoc multiple comparisons procedure was used to examine specific differences following a significant F ratio (Witte, 1980). The relationships (r) between RPE, HR and $\dot{V}O_2$ were also calculated.

RESULTS

The mean values for all variables are shown in Table I. $\dot{V}O_2$, HR, VE, and RPE were all significantly higher ($p < 0.01$) in A compared with L and A + L. E% was significantly lower in A ($p < 0.01$) than in L or in A + L. No differences were observed between L and A + L for any variable.

TABLE I

Means and standard deviations of arm (A), leg (L) and arm and leg (A + L) ergometry variables.

Variable	Power Output (W)	A	L	A + L
$\dot{V}O_2$ (l.min ⁻¹)	49.0	1.19 $\pm$ 0.07*	1.08 $\pm$ 0.07	1.10 $\pm$ 0.13
	73.5	1.70 $\pm$ 0.15*	1.39 $\pm$ 0.13	1.44 $\pm$ 0.12
	98.0	2.26 $\pm$ 0.20*	1.68 $\pm$ 0.12	1.72 $\pm$ 0.13
HR (bts.min ⁻¹)	49.0	105.00 $\pm$ 11.90*	97.00 $\pm$ 9.60	97.00 $\pm$ 11.50
	73.5	133.00 $\pm$ 20.00*	109.00 $\pm$ 11.20	104.00 $\pm$ 24.00
	98.0	155.00 $\pm$ 20.20*	121.00 $\pm$ 14.70	121.00 $\pm$ 13.40
VE (l.min ⁻¹)	49.0	32.70 $\pm$ 3.50*	25.60 $\pm$ 2.30	26.70 $\pm$ 4.30
	73.5	50.10 $\pm$ 6.70*	33.30 $\pm$ 4.80	33.50 $\pm$ 6.10
	98.0	69.00 $\pm$ 16.1*	41.10 $\pm$ 5.60	39.80 $\pm$ 4.80
E%	49.0	11.80 $\pm$ 0.60*	13.50 $\pm$ 0.80	12.90 $\pm$ 1.30
	73.5	12.50 $\pm$ 1.20*	15.60 $\pm$ 1.40	15.20 $\pm$ 1.10
	98.0	12.50 $\pm$ 1.20*	17.11 $\pm$ 1.20	16.80 $\pm$ 1.60
RPE	49.0	12.40 $\pm$ 1.20*	8.60 $\pm$ 1.70	8.10 $\pm$ 1.50
	73.5	14.90 $\pm$ 1.30*	10.60 $\pm$ 1.40	10.80 $\pm$ 1.50
	98.0	17.10 $\pm$ 1.60*	12.40 $\pm$ 0.90	12.30 $\pm$ 1.40

*Significantly different ($p < 0.01$) from L and A + L

The correlations between $\dot{V}O_2$ and $\dot{V}E$ were 0.90 and 0.86 for A and L respectively (both $p < 0.01$). Although the correlations were both highly significant, the linear regressions as seen by the lines of best fit (least squares method) were different (Fig. 1). The ventilatory equivalent was higher for A (values ranging from 28.4 to 30.7) at power output levels requiring an oxygen uptake of 1.0 and 2.0 $\text{l}\cdot\text{min}^{-1}$ respectively and 23.7 to 24.5 at similar oxygen uptake levels for L.

Fig. 1: Regression lines for $\dot{V}E:\dot{V}O_2$ for arm and leg ergometry.

$\dot{V}E$ was further analysed to compare the tidal volume (VT) and respiratory frequency (f) for A and L (Fig. 2).

Fig. 2: Comparison of rate and depth of ventilation for arm and leg ergometry.

Analysis of the $\text{RPE}:\dot{V}O_2$ ($\text{l}\cdot\text{min}^{-1}$) (Fig. 3) and $\text{RPE}:\text{HR}$ (Fig. 4) relationships for A produced r values of 0.87 and 0.78 respectively (both $p < 0.01$). The corresponding r values for L were 0.65 and 0.62 respectively (both $p < 0.01$).

DISCUSSION

There was considerable disparity between the cardio-respiratory responses for A compared to L and A + L. Mechanical efficiency (i.e. the ratio between the output of external power and caloric expenditure) was lower during A than in L and A + L. Similar values for 15 men and 15 women were observed by Hagan et al (1983) using an

Fig. 3: Regression line of predicted $\dot{V}O_2$ values for RPE.

Fig. 4: Regression line of predicted HR values for RPE.

identical ergometer. The difference in gross mechanical efficiency may well reflect the static/isometric work of the trunk and other muscles which increase $\dot{V}O_2$ but do not affect the output of external work (Bevegard et al, 1966; Cotes et al, 1969; Nag, 1982; Schwade et al, 1977).

Previous research has indicated that heart rate, cardiac output, systolic and diastolic blood pressure are all increased during isometric contractions (Lind and McNicol, 1967; McCloskey and Streatfield, 1975). The magnitude of the increase is apparently determined by the relative intensity and duration of contraction of the muscle groups (Lind et al, 1964). The higher heart rate is most likely a compensatory mechanism in response to a reduced stroke volume incurred by reduced venous return to the heart due to the orthostatic conditions (Stenberg et al, 1967).

There is also evidence to suggest an increased sympathetic outflow during dynamic arm exercise compared with dynamic leg exercise with resultant effects on (i) vasoconstriction in non-exercising muscles, (ii) blood pressure, (iii) heart rate and (iv) rate and depth of ventilation. Further supportive evidence is provided by Davies et al (1974) who observed higher levels of catecholamines per unit of oxygen uptake in A compared with L.

Although the concentration of blood lactate was not measured in this study, it has been observed from previous investigations that arm exercise using mechanically braked ergometers (Bevegard et al, 1966; Stenberg et al, 1967) or air-braked ergometers (Hagan et al, 1983) elicits higher lactate levels for any given work rate compared to L and A + L. The combination of higher lactacidaemia and increased sympathetic outflow is the most likely reason for higher VE during arm exercise in the present study. Bevegard et al (1966) have inferred that the higher VE during arm exercise could be an important factor in maintaining ventricular filling pressures and stroke volume in the absence of the mechanical effect of the leg muscle pump.

Furthermore, it has been indicated by Mangum (1984) that additional factors influencing minute ventilation may include (i) a mechanical limitation of tidal volume by static contractions of the pectoralis and abdominal musculature and, (ii) a metering or synchronisation of respiratory rate caused by the rhythmic movement of the arms.

Analysis of f and VT revealed higher values in A throughout than in the other exercise modes, but more importantly a marked increase in f relative to VT at the highest power level. Thus during more exhaustive exercise, the increased VE (a function of f and VT) is essentially attributable to respiratory rate with VT remaining constant. This is not the case at a similar absolute power output in the L condition when the two factors continued to increase at a similar rate.

RPE was significantly higher at all workloads for A compared with L and A + L. This finding agrees with previous research (Franklin et al, 1983; Pandolf et al, 1984). It has been shown repeatedly that maximum oxygen uptake obtainable by arm ergometry generally varies between 64% and 80% of leg VO_2 max (Franklin, 1985). Therefore at a given workrate an individual is working at a higher proportion of VO_2 max during arm exercise than during L or A + L. Evidence would suggest that RPE is a valid indicator of relative exercise intensity (Eston, 1984; Pandolf et al, 1984; Carton and Rhodes, 1985). Indeed, assuming that the maximal oxygen uptake is homogenous within this group, the high correlations for RPE: VO_2 and RPE:HR for A lends support to this evidence. The lower (but significant $p < 0.01$) correlations for L most probably reflect the nature of the submaximal work, in which the workrate was insufficient to attain such an accurate assessment or 'anchoring' of the level of fatigue due to the minimal nature of the local and central physiological cues.

To conclude, the results of this investigation have demonstrated that during submaximal work, exercise heart rates, oxygen uptake, minute ventilation and the rating of perceived exertion are higher and work efficiency is lower for arm work compared with leg work and compared with combined arm and leg work. These factors should be considered when using the ergometer for exercise training at specific workloads for healthy individuals, paraplegics, or patients with orthopaedic limitations or symptoms of cardiovascular disease.

References

- Bevegard, S., Freyschuss, V. and Strandell, T., 1966 "Circulatory adaptation to arm and leg exercise in supine and sitting position". *J. Appl. Physiol.* 21: 37-46.
- Borg, G.A. V., 1970 "Perceived exertion as an indicator of somatic stress". *Scand. J. Rehab. Med.* 2: 92-98.
- Carton, R. L. and Rhodes, E. C., 1985 "A critical review of the literature and ratings scales for perceived exertion". *Sports Med.* 2: 198-222.
- Cotes, J. E., Allsopp, D. and Sardi, F., 1969 "Human cardiopulmonary responses to exercise: comparisons between progressive and steady state exercise, between arm and leg exercise and between subjects differing in body weight". *Quart. J. Exp. Physiol.* 54: 211-222.
- Davies, C. T. M., Few, J., Foster, K. G. and Sargeant, A. J., 1974 "Plasma catecholamine concentration during dynamic exercise involving different muscle groups". *Eur. J. Appl. Physiol.* 32: 195-206.
- Eston, R. G., 1984 "A discussion of the concepts exercise intensity and perceived exertion with reference to the secondary school". *Phys. Educ. Review* 7 (1): 19-25.
- Fox, E. L. and Mathews, D. K., 1981. *The Physiological Basis of Physical Education and Athletics*. pp. 56-69. Philadelphia, Saunders.
- Franklin, B. A., 1985 "Exercise testing, training and arm ergometry". *J. Sports Med.* 2: 100-119.
- Franklin, B. A., Vander, L., Wrisley, D. and Rubenfire, M., 1983 "Arm exercise testing and training". *Physician and Sports Med.* 11: 81-90.
- Hagan, R. D., Gettman, L. R., Upton, S. J., Duncan, J. J. and Cummings, J. M., 1983 "Cardiorespiratory responses to arm, leg and combined arm and leg work on an air-braked ergometer". *J. Cardiac Rehabilitation* 3: 689-695.
- Lind, A. R. and McNicol, G. W., 1967 "Circulatory responses to sustained handgrip contractions performed during other exercise, both rhythmic and static". *J. Physiol.* 192: 595-607.
- Lind, A. R., Taylor, S. H., Kennelly, B. M. and Donald, K. W., 1964 "The circulatory effects of sustained voluntary muscle contraction". *Clin. Sci.* 27: 229-244.
- Mangum, M., 1984 "Research methods: application to arm crank ergometry". *J. Sports Sciences* 2: 257-263.
- McCloskey, D. I. G. and Streatfield, K. A., 1975 "Muscular reflex stimuli to the cardiovascular system during isometric contractions of muscle groups of different mass". *J. Physiol.* 250: 431-441.
- Nag, P. K., 1982 "Influence of posture and speed of arm and leg work on physiological responses". *J. Sports Med.* 22: 426-431.
- Pandolf, K. B., Billings, D. S., Drolet, L. L., Pimental, N. A. and Sawka, M. N., 1984 "Differentiated ratings of perceived exertion and various physiological responses during prolonged upper and lower body exercise". *Eur. J. Appl. Physiol.* 53: 5-11.
- Sawka, M. N., Miles, D. S., Petrofsky, J. S., Wilde, S. W. and Glaser, R. M., 1982 "Ventilation and acid base equilibrium for upper body and lower body exercise". *Aviation, Space & Environ. Med.* 53: 354-359.
- Schwade, J., Blomqvist, C. G. and Shapiro, M. D., 1977 "A comparison of the response to arm and leg work — patients with ischaemic heart disease". *Amer. Heart J.* 94: 203-208.
- Stenberg, J., Åstrand, P. O., Ekblom, B., Royce, J. and Saltin, B., 1967 "Haemodynamic response to work with different muscle groups, sitting and supine". *J. Appl. Physiol.* 22: 61-70.
- Vander, L. B., Franklin, B. A., Wrisley, D. and Rubenfire, M., 1984 "Cardiorespiratory responses to arm and leg ergometry in women". *Physician & Sports Med.* 12: 101-106.
- Witte, R. S., 1980. *Statistics*. New York, Holt, Rinehart and Winston.