A COMPARISON OF THE PEAK PHYSICAL WORK CAPACITY DURING ARM ERGOMETRY, FES CYCLING, AND TWO HYBRID EXERCISE CONDITIONS IN SPINAL CORD INJURED

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SUMMARY

The purpose of this study was to compare a newly developed functional electrical stimulation (FES) assisted rowing machine (ROWSTIM) with arm ergometry (ACE), FES cycling (CFES LE), and hybrid cranking and cycling (CFES LE + ACE). Five SCI participants (C7-T12) underwent a progressive maximal peak oxygen assessment to ascertain peak physical work capacity across 4 conditions. Three trials per exercise modality were completed to examine peak physical work capacity and to establish reliability of measurement. A one-way ANOVA with condition as the main factor showed peak absolute and relative functional aerobic capacity and heart rate to be significantly lower for CFES LE versus ACE, CFES LE + ACE and FES ROW measures ($p < 0.05$). However there were no significant differences between both hybrid exercise conditions or between hybrid exercise and arm ergometry. Preliminary results suggest that the ROWSTIM is as effective as an exercise device or training tool for SCI as FES cycling or hybrid cycling and cranking. However, a larger sample size and further technological developments of the ROWSTIM are needed to demonstrate the efficacy of rowing over upper extremity exercise and hybrid cycling and cranking.

STATE OF THE ART

Interest in enhancing exercise opportunities for persons with SCI has been mediated by evidence of increased risk for heart disease in this population./1/ One possible solution to enhance physical activity of persons with SCI is through functional electrical stimulation (FES)-assisted exercise technology. Demonstrated fitness and health related benefits of FES assisted exercise include 1) increased cardiac function, such as oxygen uptake, cardiac output and myocardial function; 2) increased venous return by activating the muscle pump below the lesion level; 3) (theoretically) reduced risk for deep vein thrombosis; 4) increased bone mineral density; 5) increased muscle area and joint range of motion; 6) increased muscle strength and endurance; 7) improved pulmonary function; and 8) increased self esteem and enjoyment of the social contact./2/ More recently research has been focused on combining FES leg ergometry with voluntary arm ergometry, referred to as hybrid exercise (HE). This theoretically augments the cardiovascular stress during exercise and consequently increases cardiovascular training effects./3,4/ Most commonly used in this hybrid approach is the addition of FES cycling to upper arm ergometry. Several studies have already demonstrated increased oxygen consumption levels and cardiovascular training effects during submaximal and maximal work compared to upper or lower extremity exercise alone./3,5,6,7,8/ Others have focused on a new form of hybrid exercise, FES rowing./5/ An FES assisted rowing machine (ROWSTM) was developed at the Robert Steadward Centre, Edmonton, Alberta by Dr Garry Wheeler and associates, to examine the potential for extending hybrid training opportunities for persons with SCI./4,9/ Studies by Laskin (1993) and later by Wheeler et al. (in press) suggest that the peak oxygen consumption measures achieved using the ROWSTIM I and II systems are comparable or superior to those reported in literature for other hybrid exercise systems. In addition, it has been demonstrated that up to 36 sessions of progressive FES rowing produces significant changes in cardiovascular fitness in spinal cord injured participants./5/ Such data are important since the FES rowing device is a much less expensive option for training and is very well tolerated and accepted by SCI participants who have used it (personal communications during the Laskin et al. (1993), the Wheeler et al. (in press) studies and this investigation).

The purpose of this study was therefore to conduct a within subject comparison of peak physical work capacity as defined by peak functional aerobic power (VO_2 peak) across 4 different types of exercise: arm crank ergometry (ACE), FES leg cycling (CFES LE), hybrid cycling and arm cranking (CFES LE + ACE) and electrical stimulation assisted rowing (FESROW).

MATERIALS AND METHODS

5 participants, 4 with complete and 1 with incomplete SCI underwent a progressive maximal peak oxygen assessment to ascertain peak physical work capacity across 4 conditions. Conditions were arm ergometry (ACE), FES cycling (CFES LE), FES cycling combined with arm ergometry (CFES LE + ACE) and FES rowing (FESROW) with 3 maximal exercise trials per exercise modality to establish reliability of measurement. Each test was preceded by a 2 minute rest. The protocols for each exercise modality were the following:

ACE: Participants were instructed to crank an arm crank ergometer (Monark Model 881, Varberg, Sweden) at 15 Watts for 2 minutes. Every 2 minutes thereafter, power output was increased by 15 Watts until voluntary fatigue. Peak functional aerobic power was defined as VO_2 at the point of failure to maintain 50 rpm arm cranking for at least 15 seconds or until the participants voluntarily stopped cranking.
CFES LE: CFES LE was performed on the ERGYS II cycle ergometer. The test protocol consisted of a 5 minute warm up with assisted pedalling. Participants were then instructed to cycle at 0 Watts for 2 minutes. Every 2 minutes thereafter cycle load was increased by 3 Watts. Peak functional aerobic power was defined as VO_2 at the point of failure to maintain 35 rpm at maximum stimulation.
CFES LE + ACE: The test protocol consisted of a combination of the ACE and the CFES LE protocol. Power output for cycling and cranking were increased every 2 minutes with 3 and 15 Watts respectively in a way that participants were both cycling and cranking simultaneously at their maximum as defined by their previous isolated ACE and CFES LE tests until fatigue. Peak functional aerobic power was defined as VO_2 at the point of failure to maintain 35 rpm cycling at maximum stimulation, failure to maintain 50 rpm cranking or until the participants voluntarily stopped cranking.
FESROW: Participants were instructed to start arm rowing at a heart rate equivalent to 40 % of their ACE functional maximum aerobic capacity. After 2 minutes, participants started arm rowing with assisted passive leg rowing at 50 % of their VO_2 max for 2 minutes. Thereafter, participants rowed (with leg stimulation) for 2 minutes at 60 % of their VO_2 max. After a 1 minute resting period, participants rowed for 2 minutes at 80% of their VO_2 max, and after another 1 minute resting period participants were instructed to row at their maximum until fatigue as defined by collapsing legs during the pull phase /5/ or if the subjects reached exhaustion.

RESULTS

VO_2 peak and HR were significantly lower for CFES LE versus ACE, CFES LE + ACE and FES ROW measures (all $p < 0.05$). VO_2 peak was consistently lower for ACE across all trials versus CFES LE + ACE and FESROW, but the reported differences were not significant ($p>0.05$). (Table 1)

	ACE	**CFES LE**	**ACE + CFES LE**	**FESROW**
VO_2 (l/min)	1.72	1.02	2.03	2.06
VO_2 (ml/min/kg)	20.47	12.23	24.28	23.79
HR (bpm)	160	103	161	162

Table 1: Mean peak absolute (l/min) and relative (ml/min/kg) VO_2, and HR (bpm) during ACE, CFES LE, CFES LE + ACE and FESROW

DISCUSSION

The need to develop exercise opportunities for persons with SCI has already been demonstrated. Ashley et al. (1993) previously suggested the ROWSTIM may be an alternative exercise solution for persons with SCI. Wheeler et al. (in press) demonstrated a 11.2 % increase in peak O_2 consumption after a 3 month progressive rowing training program. However, the only available comparison with other electrical stimulation (ES) assisted exercise modes to date was through literature data. Clearly the next step in the development of the ROWSTIM was to conduct a within subject comparison to determine peak work output from 4 different exercise modalities.

Interestingly, the data indicate how limited the potential CV training effect of cycling is. In agreement with the findings of previous studies, data show that values for hybrid training are significantly higher in comparison with the values of cycling only and clearly suggest that hybrid exercise is superior to simple leg exercise./6,10/ In addition, Hooker (1992) and Laskin (1993) demonstrated a significant difference of hybrid exercise over ACE.

ES assisted and hybrid exercise has already been associated with a number of physiological and psychological benefits. However, additional benefits of FES rowing in terms of client appreciation have also been reported. All participants preferred FES rowing over hybrid cycling and cranking as rowing was considered to be a more natural movement. In addition, since rowing utilises the shoulder retractors and muscles of lower and upper back and forearms, this exercise could have additional benefits reducing the risk of overuse and other wheelchair use related shoulder problems./5/ As well, the ROWSTIM is a minimally adapted version of an exercise tool for able-bodied people and is therefore easier and cheaper to manufacture.

However, there remain a number of considerations that have to be taken into account. Only a small sample size was used, reducing the statistical power of this investigation. Clearly a larger sample size is necessary to further demonstrate the superiority of hybrid rowing over upper extremity exercise and other hybrid training modalities. In addition, there's a number of modifications to the ROWSTIM that have to be considered. Regarding electrode placement, an attempt was made to stimulate the common peroneal nerve to facilitate the forward movement during the return phase. The authors suggest that by stimulating the common peroneal nerve a less powerful spring could be used, increasing the muscle work during training. As well, power output during rowing can not be controlled. Clearly a controllable power output would facilitate comparing hybrid and other training modalities in terms of mechanical efficiency. However, the authors suggest that with further technological developments, rowing represents a better hybrid training activity than ACE or CFES LE + ACE. A brake that would sufficiently prevent the legs from collapsing during the arm pull phase would neutralise the forward momentum originated in this phase. Consequently, leg fatigue would be delayed and exercise time and arm power output would further increase peak functional aerobic capacity. As well, a combination of hybrid exercise and upper extremity exercise alone would allow new participants to continue training while the legs are recovering. As a consequence of these technological developments, an increased arm power output and therefore a further increase in VO_2 peak by neutralising the forward momentum during the pull phase, can be expected.

CONCLUSION

Previous studies have already demonstrated the safety and efficacy of the ROWSTIM II system and suggested that this device represents a great potential for cardiovascular training for persons with SCI. This study clearly demonstrated that the aerobic demand during hybrid exercise and ACE were significantly higher than elicited during electrical stimulation assisted cycling. However, no significant differences were found between both hybrid exercise modalities and ACE. Further technological developments to the ROWSTIM II system are now necessary to further increase the metabolic demand during rowing. At present the team is working on a new break that would allow persons to train longer by minimising the force necessary to control for the forward momentum generated in the legs during the pull phase. In addition, we are confident that this break will also allow persons to train at a higher power output.

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