Chapter 6

Effects of hand cycle training on wheelchair capacity during clinical rehabilitation in persons with spinal cord injury

ABSTRACT

Objective: To evaluate the effects of a structured hand cycle training program on physical capacity in subjects with spinal cord injury (SCI) during clinical rehabilitation.

Design: Twenty subjects who followed hand cycle training were compared with matched control subjects from a Dutch longitudinal cohort study, who received usual care.

Setting: Two rehabilitation centres in the Netherlands.

Participants: n=20 patients with SCI

Intervention: A hand cycle training program (twice a week) in addition to usual care

Main outcome measures: Primary outcomes of hand rim wheelchair capacity were: peak power output (PO_{peak}), peak oxygen uptake (VO_{2peak}) and oxygen pulse. Secondary outcome measures were: isometric peak muscle strength of the upper extremities and pulmonary function. Hand cycle capacity was evaluated in the training group only.

Results: Strong tendencies for improvement were found in wheelchair capacity, reflected by PO_{peak} and oxygen pulse after additional hand cycle training. Significant effects on shoulder exo- and endo-rotation and unilateral elbow flexion strength were found but no improvements on pulmonary function.

Conclusion: Additional hand cycle training during clinical rehabilitation seems to show similar or slightly favourable results on fitness and muscle strength compared with regular care. The heterogeneous subject group and large variation in training period may explain the lack of significant effects of additional hand cycle training on wheelchair capacity.

INTRODUCTION

Clinical rehabilitation of persons with spinal cord injury (SCI) primarily focuses on achieving functional goals that contribute to a satisfactory degree of independence, participation and quality of life after discharge (Noreau and Shephard, 1995). Daily activity, however, may impose a peak strain on the upper body in persons with SCI, especially in those with tetraplegia. They generally have an extremely low physical capacity (Glaser, 1989) due to the low active muscle mass, the imbalance in thoracohumeral muscle strength (Curtis et al., 1999) and the disturbed autonomic nervous system. To deal with the strain of daily activities, it is important for persons with SCI to optimize physical capacity through regular exercise (Janssen et al., 1994). Moreover, wheelchair-bound persons are at a higher risk for secondary health problems such as pressure sores, urinary tract infections, obesity, metabolic syndrome, diabetes and cardiovascular diseases (Myers et al., 2007). Physical activity and training can help prevent some of these long-term problems. Therefore, clinical rehabilitation should not only focus on achieving functional goals but also strive for the highest possible fitness level, preferably leading to adoption of an active lifestyle (Fernhall et al., 2008). During clinical rehabilitation, various aerobic exercise modes are available to improve the physical capacity of patients with SCI: swimming, wheelchair training, fitness, and different sports such as wheelchair basketball and tennis. Not all these activities are appropriate for patients with low ability levels and at the start of active clinical rehabilitation. For example, hand rim wheelchair propulsion is a very strenuous activity because of the peak forces that occur in the shoulder and wrist joints during the short push phase (Van der Woude et al., 2001; Van Drongelen et al., 2006). Furthermore, several exercise activities (e.g. swimming) cannot always easily be performed in the own environment after discharge.

In the past decade, the add-on hand cycle has become popular for mobility and recreation in the Netherlands. Consequently hand cycling more and more is becoming an integrated part of the Dutch rehabilitation program (Valent et al., 2008; Van der Woude et al., 1986). Compared to hand rim wheelchair propulsion, hand cycling is less straining and more efficient (Dallmeijer et al., 2004b). Moreover, with the hands fixed in pedals during the full 360° cycle, forces are continuously applied in contrast to the short and technically difficult

repeated push in hand rim wheelchair propulsion (Dallmeijer et al., 1998). Therefore, hand cycling is assumed to be suitable for people with SCI during (and after) clinical rehabilitation. Two previous studies showed positive effects of hand cycle training *after* clinical rehabilitation in subjects with paraplegia (Mukherjee et al., 2001) and tetraplegia (Valent et al., submitted). A previous observational study evaluated the influence of hand cycling on physical capacity *during* clinical rehabilitation (Valent et al., 2008). After correction for baseline values and confounders (personal and lesion characteristics), a clinically relevant improvement in wheelchair capacity was found in the hand cycle group, compared to the controls. Until today, no controlled hand cycle training studies during clinical rehabilitation are available.

Based on previous studies (Valent et al., submitted; 2008), we assume that hand cycle training during clinical rehabilitation leads to both a higher hand cycling capacity and hand rim wheelchair exercise capacity. Training effects on both are expected as we assume that most upper body muscles that are active in hand cycling are also used for hand rim wheelchair propulsion.

In the current study the following hypothesis was tested: When compared to regular care, a controlled structured hand cycling program has a positive effect on wheelchair exercise capacity in subjects with SCI during clinical rehabilitation.

METHODS

Subjects

Experimental subjects

Patients of two Dutch rehabilitation centers were approached to participate in the current study. They were included if they: 1) had an acute SCI; 2) had a prognosis of 'remaining mainly wheelchair-bound'; 3) had a lesion level of C5 or lower (and consequently were expected to be able to propel a hand cycle); 4) were aged between 18 and 65 years; 5) had sufficient knowledge of the Dutch language; and 6) did not have a progressive disease or psychiatric problem; 7) were free of halo-frames or corset; 8) were made familiar with hand cycling and agreed to participate according the training protocol. Patients were excluded if they had cardiovascular contra-indications, serious musculoskeletal complaints,

or other medical complications that contra indicate exercise. After being informed about the study, the patients signed a written consent voluntarily.

Control subjects

The matched control group was selected from a large Dutch cohort study on restoration of mobility in SCI rehabilitation who received regular care (Haisma et al., 2006). Matching was based on personal and lesion characteristics (Haisma et al., 2006): age (preferably within +/-5 years and otherwise +/- 10 years), gender (male or female), lesion level (paraplegia, tetraplegia at C5 or C6, tetraplegia at C7 or C8) and motor completeness of lesion (yes or no). Subjects who were hand cycling more than once a week were excluded and data had to be available for the wheelchair maximal exercise test at the same measurement occasions (at baseline and follow-up) as for the experimental case. Finally, if more than one subject complied with these characteristics, the control subject with a baseline peak power output (PO_{peak}) most close to the baseline value of the experimental matching counterpart was chosen. This procedure was followed for all individual experimental subjects. To ensure comparable groups of subjects at pre and post-test, missing data of any of the outcomes for one of the two matched subjects led to exclusion of that pair on that outcome.

Design

Experimental subjects received hand cycle training in addition to regular care and the control subjects only received regular care (preferably without hand cycling or only occasionally). The research design included two measurement occasions: the first measurement occasion was in the week before the start of the hand cycle training program. For patients with paraplegia this was at the start of the active rehabilitation, which is defined as the moment when subjects were able to sit for 3 hours (Dallmeijer et al., 2005). Subjects with paraplegia had to start 6 weeks or 3 months later in case of halo-frames. Subjects with tetraplegia started three months after the start of active rehabilitation, because they were generally not able to perform the wheelchair test earlier in the rehabilitation period (Haisma et al., 2006). For all subjects the second measurement occasion was in the week before discharge. Outcome measures of physical capacity (wheelchair exercise capacity, muscle strength and

pulmonary function) were compared between hand cycling subjects and matched control subjects. The training group also performed a graded hand cycle capacity test, which allowed us to compare pre-and post-training.

Testing Procedure

Physical capacity

Wheelchair exercise capacity

To determine the peak power output (PO_{peak}, W) and peak oxygen uptake (VO_{2peak}, ml·min^{-1}), a graded hand-rim wheelchair exercise test was performed on a motor-driven treadmill pre and post training in both experimental subjects and controls.[1] The test protocol was previously described by Kilkens et al. (2005). During the test, the velocity of the belt was maintained constant at 0.56, 0.83 or 1.11 m·s,$^{-1}$ depending on the level of the lesion and the ability of the subject. The workload was raised every minute by increasing the slope of the belt by 0.36 degrees. The test was ended when the subject was no longer able to maintain the position and speed on the belt. The PO_{peak} was calculated from the individual drag force and treadmill belt velocity, as described by Van der Woude et al. (1986). The VO_2 was continuously measured during the test with an Oxycon Delta.[2] The highest values of PO and VO_2 maintained during the same 30 second period during the test were defined as PO_{peak} and VO_{2peak} respectively. Heart rate was continuously monitored with a heart rate monitor.[3] The cardiovascular efficiency, reflected by oxygen pulse (O_2P, ml·beat^{-1}) was calculated from VO_{2peak} and HR_{peak}: O_2P [ml·beat^{-1}] = VO_{2peak} [ml ·min^{-1}] / HR_{peak}[beats ·min^{-1}] (Wasserman K, 1999). Respiratory exchange ratio (RER) was calculated as the ratio between CO_2 and VO_2.

Muscle strength

Left and right arm muscle groups (shoulder abduction, exo- and endo-rotation and elbow flexion and extension) that scored ≥ 3 on manual muscle testing (MMT) were tested with a hand-held dynamometer (HHD),[4] according to a standardized protocol (Andrews et al., 1996). A break test was executed:

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[1] *treadmill: www.bontetechniek.nl*
[2] *Oxycon delta: www.viasyshealthcare.com*
[3] *HR-monitor Polar: www.polar-nederland.nl*

subjects had to build up a maximal force against a dynamometer after which the examiner applied a higher resistance to break through it (Phillips et al., 2000).

Pulmonary function

To assess pulmonary function, we measured and analysed the flow-volume curves with the Oxycon Delta.[2] Forced vital capacity (FVC) and the peak expiratory flow rate (PEFR) were recorded both absolute in $ml \cdot min^{-1}$ and relative to the age, gender and body weight corrected norm population (%).

Hand cycle capacity

To determine hand cycling capacity, reflected by PO_{peak} and VO_{2peak}, an additional discontinuous graded hand cycle exercise test was executed 2-3 days after the wheelchair peak exercise test on a motor driven treadmill. The test protocol was previously described by Valent et al. (2007). The experimental velocity was adjusted to the ability of the subject, but within the range of 1.11-1.94 $m \cdot s^{-1}$ and a gear setting resulting in a cadence of approximately 60 rpm. Exercise bouts of two minutes were interspaced with a rest period of 30 s. Each exercise step the workload was increased with 2.00-5.25 W using a pulley system (Valent et al., 2007) until exhaustion was reached. VO2 and HR were measured continuously during the test.

Training

The add-on hand cycle

The wheelchair-hand cycle unit was provided by the rehabilitation centre and adapted to the anthropometry of the individual. The add-on hand cycle unit (executed with cranks and a wheel) can be attached to the front of the hand rim wheelchair.[5] The crank pedals move synchronously with alternating elbow/shoulder flexion and extension of both arms. Most of our hand cycles were equipped with wide bull-horn cranks which allow positioning of the crank axis as low as possible, slightly above the upper legs and consequently the pedals can move alongside the knees (in the lowest position). The hand cycle is equipped with gears that can be changed manually or with the chin.

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[4] *Microfet:www.biometrics.nl*
[5] *www.doubleperformance.nl*

Training protocol

Subjects with paraplegia started the hand cycle training program at the start of active rehabilitation and those with tetraplegia started three months later. Both continued training twice a week until discharge. The duration of training sessions was between 35 and 45 minutes (including a short warm-up and cool-down session). Most of the time, we trained outside with the group on cycle tracks and in case of bad weather we trained inside. For practical reasons the sessions were always scheduled at the end of the day. The rating of perceived exertion had to be between 4-7 on the Borg's 10-point scale (Noble et al., 1983). From a previous study in untrained subjects with tetraplegia (in the post-clinical period) interval training appeared to be more suitable than continuous aerobic training (Tordi et al., 2001; Valent et al., submitted) In the first practice sessions of our subjects with tetraplegia we used bicycle indoor equipment[6] adjusted for hand cycling to ensure a low initial power level. At the start of the training program, subjects with tetraplegia had to be able to hand cycle continuously for approximately 2 minutes. Pre-training sessions were performed until the subjects were able to achieve this. The first training sessions involved interval training with several 1 to 2-minute blocks of hand cycling, followed by 3 to 4 minutes of rest. During the course of the training period, the hand cycling blocks could be gradually increased to 3 to 4 minutes while rest blocks reduced to 1 to 2 minutes. Persons with paraplegia were able to start with an interval-training schedule of 3 to 4 minutes exercise with 1 to 2 minutes rest in between. In these subjects, the rest period gradually changed into "active rest" (cycling at a lower intensity, i.e. velocity) as fitness level improved. No other demanding aerobic exercise training was performed on training days and at least two days were scheduled in between training days. Subjects were asked to make up for a missed training session if possible. Subjects were asked to maintain a training diary and to report pain and/or complaints to the upper extremities, as well as their rating of perceived exertion on the Borg scale immediately after the training sessions. If serious complaints to the upper extremities or illness occurred, the subjects were asked to contact the trainer/researcher before continuation of the training.

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[6] *Bicycle indoor trainer; Minoura Magturbo: www.minoura.jp*

Statistical analyses

The pre- and post-test outcomes of the experimental subjects were compared with the pre and post-test outcomes of the matched control subjects using ANOVA for repeated measures, analyzing the interaction of measurement (pre and post test) and group (training and control). P-value was set at 0.05.

RESULTS

Subjects

Twenty subjects were included in the study (Table 1). Three subjects dropped out after the pre-test for various reasons, not related to hand cycle training (depressive disorder, severe neurological pain, tendonitis elbow). The baseline characteristics of our experimental group (and control group) only differed on age (46 ± 15 yrs and 40 ±14 yrs respectively) from those of the longitudinal Dutch cohort group (Haisma et al., 2006).

We were able to find matched control subjects among the longitudinal cohort group that complied with our matching criteria for subject characteristics for all 17 remaining experimental subjects. For one subject with a C8-lesion (#14) no control subject with a C7 or C8-lesion was available and we selected a control with a Th3-lesion. Table 1 describes the personal and lesion characteristics of the experimental and control group and gives information on training compliance. The length of the active rehabilitation period, other sports activities (fitness, swimming and wheelchair sports) and PO_{peak} baseline –values were comparable between both groups.

Table 1: Personal and lesion characteristics of the experimental and control group

	Lesion level PP TP	AIS AB CD	gend M F		age	body mass	active rehab	other aerobic activities	PO_{peak} wheelchair at baseline	Training compl sessions	missed sessions
	n n	n n	n n		yrs	kg	weeks	hours/wk	W		%
Train group	10 7	11 6	13 4	range	22-65	50-107	9-39	0-2	9.0-54.6	15-72	7-17
				mean	46±15	74.5±14	17±8	1.3±0.6	29.5±13.5	32±16	13±3
Contr group	11 6	11 6	13 4	range	19-62	49-95	5-47	0-4	10.1-63.0		
				mean	45±15	77±12.5	18±11	1.2±1.2	30.5±18.1		
	17	17	17	*p*	0.408	0.665	0.654	0.649	0.740		

Train group: training group, contr. Group: control group, PP: paraplegia, TP: tetraplegia, AIS: ASIA-Impairment Scale: A and B: motor complete, C and D: motor incomplete, gend: gender, M: male, F: Female, active rehab: active rehabilitation.

Training

No chronic overuse injuries were reported associated to the hand cycle training. Subjects occasionally reported muscle soreness but generally recovered well from the training sessions. The training period varied from 9 to 39 weeks. Consequently, the total number of training sessions also varied substantially between subjects: from 16 to 31 sessions in persons with paraplegia, and 15 to 72 sessions in subjects with tetraplegia. Subjects missed on average 13 ± 3% of the training sessions during the training period (Table 1). Reasons mentioned were medical conditions such as flu, urinary tract infections, autonomic dysregulation and pressure sores. In the training diaries the subjects reported a perceived exertion of 4-7 on the 10-point Borg-scale.

Outcome measures

Results for all outcome measures are shown in Table 2. Subject numbers differed among outcome measures because of various reasons: two subjects (#1 and #10) were not able to perform the wheelchair exercise tests at either occasions due to spasticity and lack of arm strength (or left-right strength differences). In two subjects (# 5 and #9) we missed data on the post hand cycle test because of an unexpected early discharge. We missed data on the wheelchair and hand cycle tests in one subject (#11) due to the inability to keep a constant velocity on the treadmill. Furthermore, it was not possible to measure strength of all muscle groups due to paralysis or due to pain provoked by muscle testing. In addition, if an experimental or his matching control subject missed data on an outcome value, than both subjects were excluded from analysis, e.g. the low number of subjects on HR_{peak} can be explained by missing data in the control subjects.

Table 2: Results of the experimental and control group comparison (repeated measures anova) of outcome measures

		Experimental group			Control group		repeat. meas. ANOVA		
		pre-test	post-test	N	pre-test	post-test	interact	time	group
Wheelchair capacity	N			N				p-value	
PO_{peak} (W)	14	30.7 ± 14.0	41.9 ± 16.6	14	32.8 ± 18.6	40.1± 20.8	0.079	0.000	0.983
PO_{peak} (W·kg^{-1})	14	0.43 ± 0.19	0.58 ± 0.22	14	0.45 ± 0.24	0.54 ± 0.28	0.070	0.000	0.890
VO_{2peak} (ml·min^{-1})	13	1.06 ± 0.32	1.27 ± 0.37	13	1.03 ± 0.38	1.16 ± 0.38	0.356	0.001	0.584
VO_{2peak} (ml·kg·min^{-1})	13	14.8± 3.9	17.7 ± 4.4	13	14.0± 5.3	15.5 ± 6.0	0.274	0.01	0.498
RER	13	1.03 ± 0.11	1.11± 0.16	13	1.03 ± 0.07	1.10 ± 0.18	0.760	0.040	0.974
HR_{peak} (beats·min^{-1})	10	136 ± 27	139 ± 27	11	136 ± 29	142 ± 31	0.568	0.139	0.911
O_2 pulse (ml·beat^{-1})	9	7.9 ± 2.2	9.0 ± 2.4	9	7.5 ± 2.4	7.6 ± 2.5	0.052	0.037	0.436
Arm strength (HHD)									
elbow flexion (N) R	13	253 ± 94	283 ± 91	13	213 ± 73	233 ± 72	0.500	0.002	0.168
elbow flexion (N) L	12	255 ± 76	300 ± 84	12	235 ± 75	233 ± 65	0.010	0.016	0.160
elbow extension (N) R	11	146 ± 66	173 ± 62	11	160 ± 64	171 ± 59	0.119	0.001	0.815
elbow extension (N) L	11	151 ± 70	174 ± 71	11	166 ± 54	183 ± 63	0.608	0.000	0.534
shoulder exorotation (N) R	14	126 ± 47	150 ± 49	14	130 ± 43	134 ± 33	0.011	0.001	0.730
shoulder exorotation (N) L	14	124 ± 47	154 ± 51	14	129 ± 43	133 ± 43	0.001	0.000	0.646
shoulder endorotation(N) R	14	158 ± 71	191 ± 70	14	149 ± 54	160 ± 61	0.025	0.000	0.396
shoulder endorotation(N) L	13	165 ± 62	195 ± 62	13	158 ± 61	163 ± 67	0.026	0.004	0.417
shoulder abduction (N) R	13	163 ± 50	184 ± 48	13	151 ± 49	160 ± 54	0.222	0.008	0.349
shoulder abduction (N) L	13	166 ± 57	191 ± 62	13	155 ± 53	165 ± 47	0.176	0.005	0.389
Pulmonary function									
FVC (%)	16	76.0 ± 24.6	85.4 ± 19.6	16	77.0 ± 24.3	84.8 ± 21.3	0.619	0.000	0.983
PEF (%)	16	65.8 ± 27.1	78.4 ± 21.1	16	59.7 ± 19.7	69.7 ± 19.1	0.722	0.004	0.291

PO_{peak}: peak power output, VO_{2peak}: Peak oxygen uptake, RER: respiratory exchange ratio, O_2P: peak oxygen pulse = $VO_{2peak} ·HR_{peak}^{-1}$, FVC: Forced Vital Capacity, PEFR: Peak Expiratory Flow Rate, HHD: Hand-held dynamometry, N: Newton, R: Right, L: left.

Wheelchair exercise capacity

Although no significant effect of hand cycle training was found for the training versus control group on the outcome measures of wheelchair capacity, positive trends were found for PO_{peak} and oxygen pulse with p-values of 0.079 and 0.052, respectively (Table 2). No significant effect of hand cycle training was found for VO_{2peak}. After correction for body mass, again a trend (p=0.070) was found for PO_{peak} (W·kg^{-1}), but no effect on VO_{2peak} (ml·min^{-1}·kg^{-1}).

Muscle strength

As is shown in Table 2, significantly larger improvements were found in the experimental group compared to the control group for muscle strength of elbow flexion (only left), shoulder exo-rotation and shoulder endo-rotation (both left and right). No training effect was found for the other muscle groups.

Pulmonary function

No significant training effects of hand cycling were found for pulmonary function.

Hand cycle capacity

Comparing pre- with post-test results in the training group only, we found substantial improvements in PO_{peak} (p=0.000) (Figure 1a), but only a trend for improvement in VO_{2peak} (p=0.065) (Figure 1b).

Figure 1a and 1b: pre and post test results of PO_{peak} and VO_{2peak} in the hand cycle test (experimental group) and in the wheelchair (experimental and control group)
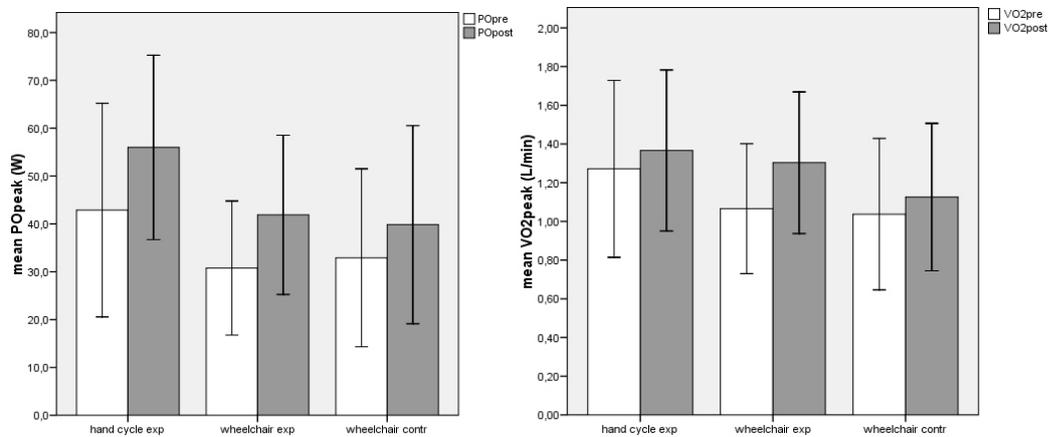
PO_{peak}: Peak power output, VO_{2peak}: peak oxygen uptake, POpre: PO_{peak} in pre-test, VO_2pre:VO_{2peak} in pre-test, POpost: PO in post-test, VO_2post:VO_{2peak} in post-test, exp: experimental, contr: control.

DISCUSSION

The aim of this study was to determine the effect of structured hand cycle training twice a week in comparison with usual care during active rehabilitation of persons with SCI. Although a strong tendency for an improvement in wheelchair exercise capacity, reflected by borderline effects in PO_{peak} and oxygen pulse, was found in the training group in comparison to the regular care group, there was no significant improvement in VO_{2peak}. However, we did find significantly larger improvements of arm muscle strength in the training subjects compared to the controls, whereas no training effect was seen in pulmonary function.

Training effects

Although a strong tendency was found for an improved PO_{peak} (p=0.079) after HC-training in the current study, the positive effects on PO_{peak} and VO_{2peak} of a previous non-controlled hand cycle training study during clinical rehabilitation could not be confirmed (Valent et al., 2008). Oxygen pulse, available in a subgroup of only 9 (pairs of) subjects, improved nearly significant (p=0.051) suggesting some improvement in cardiovascular efficiency.

It is difficult to compare our results on PO_{peak} and VO_{2peak} with the few studies that focused on the effects of structured upper body training programs during clinical rehabilitation of subjects with recent SCI (De Groot et al., 2003; Hjeltnes and Wallberg-Henriksson, 1998; Knuttson E, 1973; Le Foll-de Moro et al., 2005; Sutbeyaz et al., 2005). Like the current study, previous studies involved small and heterogeneous subject groups but in contrast, they were without a control group receiving regular care/treatment (De Groot et al., 2003; Hjeltnes and Wallberg-Henriksson, 1998; Knuttson E, 1973; Le Foll-de Moro et al., 2005; Sutbeyaz et al., 2005). Moreover, it seems more valid to conclude that the improvements of these studies were the result of the total rehabilitation program whereas our focus was on the additional effect of hand cycle training to regular care.

Peak arm muscle strength, especially of shoulder exo-rotation and endo-rotation, improved significantly more in the hand cycling group compared to the control subjects. These improvements of more than 10% are considered clinically relevant according Brehm et al. (2004) but were not in agreement with the muscle groups in a previous study in which only a significant improvement in elbow extension strength in patients with paraplegia was found after hand cycling (Valent et al., 2008). However, the latter observational cohort study was not a controlled training study like the current study. Another experimental training study in subjects with tetraplegia found small significant gains in some muscle groups (e.g. shoulder abduction) after a structured hand cycle training (Valent et al., submitted). This study however, involved subjects with chronic tetraplegia more than 2 years after discharge. Although our training protocol was not primarily designed to train muscle strength, the interval protocol appeared to allow a significant contribution to shoulder muscle strength.

Pulmonary function improved in the HC group over time but no improvements were found that could be attributed to hand cycling alone. These findings were in agreement with previous aerobic upper body training studies from which it seems that clinically relevant improvements (>10%) (Brehm et al., 2004) in pulmonary function are not commonly found (Taylor et al., 1986; Valent et al., submitted; Valent et al., 2008; Yim, 1993).

Hand cycle and wheelchair capacity

In terms of test-specificity, it makes more sense to evaluate hand cycle training in a hand cycle test than in a wheelchair since hand cycling is more efficient than hand rim propulsion. Relatively larger gains in PO_{peak} are more likely to be found in the hand cycle test. Unfortunately, data on hand cycle capacity was not available in the control subjects. Nevertheless, the mean relative changes in PO_{peak} and VO_{2peak} of the hand cycle test of subjects in the training group were of the same magnitude as in the wheelchair test, suggesting that training effects were comparable. Some transfer of the hand cycle training effect may be expected since all our subjects also participated in other therapies focussing on daily hand rim wheelchair use and training. At least part of the upper body musculature that is trained in hand cycling will be used in hand rim wheelchair propulsion.

Both in the wheelchair and hand cycle test, our experimental subjects had gains (%) in PO_{peak} that were approximately 3 times higher than gains (%) in VO_{2peak}. The relatively greater improvement in PO_{peak} over the increase in VO_{2peak} is in agreement with other studies on the effects of clinical rehabilitation in persons with SCI (Haisma et al., 2006; Hjeltnes and Wallberg-Henriksson, 1998; Valent et al., 2008). The relatively high gains in PO_{peak} compared with VO_{2peak}, suggest an improved mechanical efficiency (i.e. skill, coordination) in both wheelchair propulsion and hand cycling during clinical rehabilitation; probably as a consequence of an improved exercise technique (muscle coordination of the arms and shoulders) and/or a local adaptation in muscle metabolism (Hjeltnes and Wallberg-Henriksson, 1998). The higher VO_{2peak} and PO_{peak} -values in the hand cycle test compared to the wheelchair test are expected to be a result of the differences in test-protocols (discontinuous vs. continuous) and -mode (hand cycle vs. hand rim).

Although continuous and discontinuous arm crank protocols yielded comparable results in able bodied (Washburn and Seals, 1983), especially our hand cycling subjects with tetraplegia may have performed better thanks to the discontinuous protocol. This is based on a previous study in which muscle fatigue (often mentioned as reason for stopping) was delayed by including short rest intervals (Valent et al., submitted). Hand cycling (as test mode) is more efficient (Dallmeijer et al., 2004b) and easier than wheelchair propulsion (Dallmeijer et al., 1998). In addition, we noticed that when propelling their wheelchair, several subjects had difficulty to keep a straight line due to muscle strength differences (right and left-side) or spasticity. These problems did not occur during hand cycling on a treadmill. Based on these results, hand cycling seems a more favourable mode of exercise testing than hand rim wheelchair propulsion.

Training

Most subjects were very motivated to follow the sessions and an important motivation for participation was the opportunity to be outside (out of the centre). The training protocol appeared to be well sustainable for all subjects.

As there were only two training sessions weekly there seemed to be enough time to recover from the specific hand cycle training. However, it occurred that the hand cycle session (scheduled as the last therapy of the day) was missed because subjects were ill, too tired or had mild over-use complaints due to other therapies and/or due to strenuous activities like making transfers etc. The reported non-compliance (on average 13%) is a phenomenon typically seen in training studies in (untrained) persons with recent SCI (Chapter 2). This can be explained by the vulnerable condition of the SCI-patients during the clinical period as a consequence of the preceding inactive bed-bound period and unstable medical conditions resulting in e.g. urinary tract infections, bowel problems, orthostatic hypotension or autonomic dysregulation (Haisma et al., 2007b).

Three subjects with tetraplegia stayed in the rehabilitation centre for a long period and thus also had a longer period of hand cycle training. Although all three improved substantially, it is not justified to conclude that more hand cycle training sessions lead to more improvement; the larger gain may also be attributed to the longer period in the rehabilitation centre (and participation in

other therapies). The latter however, is in contrast with Haisma et al. (2007a) who found that, within the Dutch cohort group, a longer rehabilitation period was negatively associated with fitness improvements or recovery over time. It appeared that long staying patients (who had achieved functional goals) were mainly waiting in the last phase of rehabilitation until post discharge facilities - e.g. home adaptations and assistive equipment -were arranged whereas training goals were subordinate.

Limitation of the study

The design of the current study is not optimal, which is a randomized clinical trial. We did match our experimental subjects with controls but it is unclear whether they did not hand cycle regularly because it was not offered to them, due to lack of interest, or due to physical or medical problems creating selection bias. However, it was found that the experimental and control group had comparable mean baseline-values of PO_{peak}, therefore we regarded the controls as valid counterparts.

From the current study, it appeared that the subjects trained less than the planned frequency. Together with a short training period, some subjects probably did not complete enough training sessions to benefit from the hand cycle training. For example, we noticed that one subject (# 14 with a C8-lesion) had a short rehabilitation period and completed only 15 training sessions. As in all subjects with tetraplegia, we included this subject after three months of active rehabilitation. He had managed to improve in fitness considerably in the first three months and started with a relatively high baseline level, which may explain his early discharge and the fact that he was the only subject showing no improvements on PO_{peak} during both wheelchair (and hand cycle) tests. It appeared that excluding this subject from the analysis, a significant improvement in PO_{peak} ($p=0.034$) was found on wheelchair capacity. We were only able to evaluate wheelchair or hand cycle capacity in 5 out of 7 subjects with tetraplegia, although from training we saw that all 7 subjects managed to build up their hand cycling capacity; from a few meters to a few km outside. To conclude, the (positive) effects of hand cycle training in the current study might be underestimated due to the small and heterogeneous subject group and due to missing values.

Recommendations

Based on the results in the current study, it is safe for persons with SCI to start hand cycle training in the beginning of active rehabilitation. Although (for reasons of exercise testing) we started later in subjects with tetraplegia, we think it is wise to start with preparing and practising hand cycling as soon as active rehabilitation begins. To prevent over-use injuries, it is advised to prevent any activity above shoulder level by placing the crank axis as low as possible.(Bonninger et al., 2005; Valent et al., submitted) It is also advised to hand cycle synchronously, as the mechanical efficiency appears to be significantly higher compared to asynchronous hand cycling (Bafghi et al., 2008; Dallmeijer et al., 2004a). Patients with tetraplegia, are advised to start training with an indoor trainer or a well-adapted arm crank device, to allow the use of low initial power levels. Furthermore, we recommend the use of interval training protocols to build up fitness in wheelchair-bound persons with a low initial physical capacity (Tordi et al., 2001; Valent et al., submitted). Moreover, the recovery time in between hand cycling blocks reduces the repetitive strain on the musculoskeletal system and thus prevent the occurrence of overuse injuries (Bonninger et al., 2005).

In conclusion, to overcome barriers holding persons with SCI back from future hand cycling, rehabilitation programs should also focus on functional and independent hand cycle use in the own environment. More research in persons with SCI is needed to optimize and integrate aerobic training protocols and modes (e.g. hand cycling) in the rehabilitation program.

CONCLUSIONS

Compared to matched controls receiving regular care, we found a tendency for improvement in PO_{peak} and oxygen pulse after structured hand cycle training. In addition, we found positive effects of hand cycling on muscle strength of shoulder endo-rotation and exo-rotation but no effect on pulmonary function. No adverse effects of hand cycling were found. Therefore, compared with usual care during clinical rehabilitation, hand cycling seems to be a safe exercise mode for persons with SCI to build up fitness and muscle strength, showing similar or favourable results. The heterogeneous group of subjects and missing

values, together with a large variation in length of the training period may have affected statistical power of this study.

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