Chapter 5

The effects of hand cycle training on physical capacity and health-related quality of life in individuals with tetraplegia

ABSTRACT

Objective: To evaluate the effects of a structured hand cycle training program in individuals with chronic tetraplegia.

Design: Pre- (t1) and post (t2) outcome measures on physical capacity and health-related quality of life were compared.

In addition, double baseline data (t0, t1) were available for a subgroup.

Setting: Structured hand cycle interval training at home or in a rehabilitation centre in the Netherlands.

Participants: Untrained to moderately trained subjects with tetraplegia; time since injury > 2 yrs (n=22)

Intervention: An 8-12 week hand cycle interval training program

Main outcome measures: Primary outcomes were: peak power output (PO_{peak}) and peak oxygen uptake (VO_{2peak}) as determined in hand cycle peak exercise tests on a motor driven treadmill. Secondary outcome measures were: peak muscle strength of the upper extremities (with hand-held dynamometry), pulmonary function (forced vital capacity and peak expiratory flow) and health-related quality of life (SF36).

Results: We found a statistically significant effect of the structured hand cycle training on physical capacity as reflected by PO_{peak} and $VO_{2peak.}$ Except for abduction, no significant effects were found on muscle strength, spirometric values or quality of life.

Conclusion: Despite dropouts and non-compliance (due to health and practical problems), untrained subjects with tetraplegia were able to improve their physical capacity through regular hand cycle interval training.

Key Words: Spinal cord injury, peak oxygen uptake, peak power output, sub maximal oxygen uptake, muscle strength, pulmonary function.

INTRODUCTION

The physical capacity of most people with a cervical spinal cord injury (SCI) is low (Glaser, 1989). Additional to the complete or incomplete paralysis many other factors may contribute to the low physical capacity of this group. Persons with tetraplegia have a disturbed sympathetic nervous system that might lead to bradycardia, orthostatic hypotension, autonomic dysreflexia, temperature dysregulation and sweating disturbances (Krassioukov et al., 2007). Depending on the location and severity of the lesion, cardiovascular responses to exercise (e.g. increased blood flow to active muscles and vasoconstriction in relatively inactive tissues) may be disturbed (Glaser, 1989; Krassioukov et al., 2007). Secondary complications like urinary tract infections, spasms, pressure sores or overuse injuries in the upper extremity may also lead to inactivity and deconditioning. Other barriers for physical activity are both intrinsic, such as lack of energy or motivation, as well as extrinsic, such as costs, not knowing where to exercise, accessibility of facilities and knowledgeable instructors (Scelza et al., 2005). Interestingly, also concerns that exercise may be too difficult and even health concerns kept those with tetraplegia from exercising (Scelza et al., 2005). Deconditioning may eventually lead to additional health problems such as obesity, diabetes and cardiovascular problems (Myers et al., 2007). Therefore, it is suggested that a certain level of physical activity and fitness is important for persons with tetraplegia to maintain (or even improve) functioning, participation, health and quality of life (Noreau and Shephard, 1995).

Hand-rim wheelchair propulsion and hand cycling (in contrast to arm cranking) are functional modes of regular daily mobility that are assumed to help persons with tetraplegia to maintain a physically active lifestyle. Hand rim wheelchair propulsion is however highly inefficient (Van der Woude et al., 2001) and straining, often leading to upper extremity overuse problems (Curtis et al., 1999). For persons with tetraplegia it may even be difficult to apply a well-directed force during every push (Dallmeijer et al., 1998). For them, hand cycling may be easier to perform than hand rim wheelchair propulsion. The hands are fixed in pedals with special grips and forces can be continuously applied over the full 360^{o} cycle in both push and pull phase. In contrast, during hand rim wheelchair propulsion, force can only be applied in 20-40% of the cycle (Van der Woude et al., 2001). In addition, Dallmeijer et al. (2004) found, in subjects with paraplegia, a higher mechanical efficiency and peak power output in hand cycling compared to hand-rim wheelchair propulsion. According to clinical experience, persons for whom hand rim wheelchair propulsion is too strenuous, appear to be able to hand cycle a few hundred meters after only a few practising sessions.

Only few intervention studies are available on the effects of upper body training in persons with tetraplegia (Valent et al., 2007a). These studies were executed using different modes of arm exercise: arm cranking (DiCarlo, 1988; McLean and Skinner, 1995), wheelchair propulsion (Whiting RB, 1983), circuit resistance training (Cooney and Walker, 1986) or quad rugby (Dallmeijer et al., 1997). Furthermore, the ergonomics of arm cranking in the above-mentioned studies (DiCarlo, 1988; McLean and Skinner, 1995) differs substantially from hand cycling in the current study: i.e. asynchronous arm cranking versus synchronous hand cycling and a high versus low position of the crank axis, respectively.

Except for one training study (Dallmeijer et al., 1997), none of the studies included a (randomised) control group and the effects of training on physical capacity were not consistent (Valent et al., 2007a). Training studies on the effects of hand cycling in persons with SCI are even more scarce with only one study in subjects with paraplegia (Mukherjee et al., 2001) and no studies in subjects with tetraplegia. In a recent observational study on the influence of hand cycling during and one year after clinical rehabilitation, we found clinically relevant improvements in physical capacity (in PO_{peak} and VO_{2peak}) in patients with paraplegia during rehabilitation, but not in patients with tetraplegia probably due to small and heterogeneous groups (Valent et al., 2008).

The aim of the present study was to evaluate the effects of a structured hand cycle interval training intervention on physical capacity and health-related quality of life in persons with tetraplegia at least 2 yrs post-injury. It was hypothesized that a structured hand cycle training intervention significantly improves physical work capacity (reflected by the primary outcomes PO_{peak}, VO_{2peak} and secondary outcomes pulmonary function and arm muscle strength) and health-related quality of life.

METHODS

Subjects

Former patients with chronic cervical SCI of three Dutch rehabilitation centers were approached to participate in the current training study. Subjects were included if they 1) had been discharged from clinical rehabilitation more than one year ago and had a time since injury (TSI) of at least 2 yrs, 2) had a motor (in)complete C5-C8 lesion, 3) were wheelchair bound 4) received physical training for less than 2 hours a week over the past 3 months, 5) were between 18 and 65 yrs of age, 6) had sufficient knowledge of the Dutch language. A physician medically screened all subjects. Exclusion criteria were: severe (overuse) injuries of the upper extremities, secondary health problems (i.e. pressure sores, bladder infections, cardiovascular diseases or contra-indications according to American College of Sports Medicine (ACSM) guidelines) or other medical conditions that did not allow performing physical activity. Approval was obtained from the local Medical Ethics Committee and all subjects signed an informed consent form.

Design

The pre-post training design involved a pre-training test, one week before the start of the 8-12 week training period (t1), and a post-training test, one week after the end of the training period (t2). In a subgroup we had the opportunity to do a control test approximately ten weeks before the start of the training period (t0). The double baseline design in this subgroup thus involved three measurement sessions: t0, t1 and t2.

Peak power output and peak oxygen uptake during the hand cycle peak exercise test were the primary outcome measures of physical capacity. In addition, muscle strength, pulmonary function and health-related quality of life were evaluated at all measurement occasions as secondary outcome measures.

Intervention: hand cycling

The add-on hand cycle

Subjects used an add-on hand cycle system (equipped with bull horn shaped cranks and a front wheel) which is coupled to the front of the regular everyday hand rim wheelchair.[1] The two small front wheels of the wheelchair are lifted and the hand cycle wheel in front together with the two rear wheels of the wheelchair form the hand cycle. The crank pedals move synchronously with alternating flexion and extension of the arms. In contrast to conventional straight cranks, the wide bullhorn cranks allows the crank axis to be positioned as low as possible, slightly above the upper legs and consequently the pedals can move alongside the knees (in its lowest position). The hand cycle is equipped with gears that can be changed manually or by moving the chin forward/backward to the switches.

Training protocol

Since not all persons in the current study were acquainted with hand cycling, three practice sessions were executed once a week in the three weeks before the control test. The hand cycle interval training protocol was structured in intensity, frequency and duration. For all subjects we aimed at a total of 24 training sessions within a continuous period of 8 to 12 weeks. Those subjects who were using a hand-rim wheelchair as primary mode of mobility were assumed to be able to keep a training frequency of 3 training sessions a week for eight weeks. Those who used an electrical wheelchair were advised to train twice a week for 12 weeks. All subjects were asked to continue there regular other physical activities and to make up for a missed training session if possible. Depending on their personal situation, subjects had the opportunity to train in the rehabilitation centre or at home and both indoors and outdoors. To ensure training in case of bad weather conditions, those who were training at home also received bicycle indoor equipment that was adjusted for hand cycling[2] The duration of one training session was between 35 and 45 minutes (including a short warming-up and cooling-down session). In the first week of training, the sessions consisted of six repetitions of 3 minutes of hand cycling followed by a 2 minutes rest interval. During the training period the number of repetitions increased to eight and the hand cycle time of each block increased to 4 minutes, while resting time decreased to one minute (Appendix 1). To avoid

---

[1] *Hand cycle attach unit with bullhorn steer: www.doubleperformance.nl*

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

muscle fatigue or injury, at least one day of rest was scheduled in between training days. During training, subjects were monitored on heart rate which allowed them to train according to the prescribed personal heart rate intensity, as well as to evaluate whether the training was well sustainable (Valent et al., 2007b). Training intensity was intended to range between 60-80% heart rate reserve (HRR $=HR_{peak} - HR_{rest}$ as determined during the exercise test). Perceived exertion was monitored using the Borg's 10 point scale and was intended to range between 4-7 for training (Noble et al., 1983). In order to report pain and/or complaints to the upper extremities immediately after the training sessions as well as to report their rating of perceived exertion on the Borg scale, subjects were asked to keep a training diary. If serious complaints to the upper extremities or illness occurred the subjects were asked to contact the trainer/researcher before continuation of the training.

Outcomes

Physical capacity

Prior to testing, subjects were asked to empty their bladder to help prevent possible bouts of autonomic dysreflexia. Heart rate and oxygen uptake during rest (HR_{rest} and VO_{2rest}) were monitored during five minutes of quiet sitting. Subsequently, subjects were familiarized with the hand cycle on the treadmill [3] and 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. Mean sub maximal oxygen uptake ($VO_{2submax}$) and heart rate (HR_{submax}) were measured at a constant load in the last 30 seconds of a 3-minute sub maximal hand cycle bout. Since velocity and gear were kept the same during all measurement occasions, PO_{submax} was comparable between measurements and a lower $VO_{2submax}$ would indicate an increased mechanical efficiency.

After three minutes of rest, peak power output (PO_{peak}, W), peak oxygen uptake (VO_{2peak}, $ml{\cdot}min^{-1}$) and peak heart rate (HR_{peak}, $beats{\cdot}min^{-1}$) were determined in a discontinuous graded peak exercise test performed in the hand cycle on a motor-driven treadmill (Appendix 1; Figure 1). Exercise bouts of two minutes

[3] *treadmill: www.bontetechniek.nl*

were interspaced with a rest-period of 30 s. After each exercise step, the workload was increased by adding additional resistance (F_{add}) to the back of the hand cycle by means of a pulley system (Dallmeijer et al., 2004). Increments of 2.00-5.25 W (depending on the level of the lesion and the ability of the subject) were imposed until exhaustion was reached or until the subject indicated that he/she wanted to stop. The test protocol was previously described by Valent et al.(2007b). Rolling resistance (F_{rol}) of the individual hand cycle-user combination on the treadmill was determined in a drag-test on the treadmill (Van der Woude et al., 1986). The PO was calculated from the separately measured individual drag-force (F_{rol}; N), the additional resistance (F_{add}; N) and treadmill belt velocity (v; $m{\cdot}s^{-1}$):

$$PO = (F_{rol} + F_{add}) * v \qquad [W]$$

During the test, VO_2 was measured continuously with an Oxycon Delta.[4] The highest average 30 sec values of PO and VO_2 during the test were defined as PO_{peak} and VO_{2peak}. Heart rate was continuously monitored with a heart rate monitor[5] and HR_{peak} was defined as the highest heart rate recorded in a 5 sec interval. The cardiovascular efficiency, reflected by the oxygen pulse (O_2P, $ml{\cdot}beat^{-1}$) was calculated from VO_{2peak} and HR_{peak} (O_2P [$ml{\cdot}beat^{-1}$] = VO_{2peak} [ml $\cdot min^{-1}$] / HR_{peak}[beats $\cdot min^{-1}$]) (Wasserman K, 1999).

Muscle strength

Arm muscle groups (elbow flexion and extension, shoulder exo- and endorotation and abduction) that scored ≥ 3 on manual muscle testing (MMT) were tested with hand-held dynamometry (HHD),[6] according to a standardized protocol (Andrews et al., 1996). A break test was executed in which the subjects built up a peak force against a dynamometer after which the examiner applied a sufficiently higher resistance to break through it (Phillips et al., 2000). The peak force of the left and right side muscle groups were summed. Only subjects with

[4] *Oxycon delta: www.viasyshealthcare.com*
[5] *HR-monitor Polar: www.polar-nederland.nl*
[6] *Microfet:www.biometrics.nl*

a strength-score for both left and right side for a certain muscle group were included in the strength analysis.

Pulmonary function

To assess training effects on pulmonary function we measured and analysed simple spirometric values with the Oxycon Delta:[4] Forced vital capacity (FVC) and the peak expiratory flow (PEF) were recorded both in $ml \cdot min^{-1}$ and relative to the age, gender and body weight corrected norm population (%).

Health-related quality of life

Health-related quality of life (QOL) (Wood-Dauphinee et al., 2002) was scored on three out of eight domains of the SF-36: Mental Health, Vitality and perceived General Health.

Adverse effects

Pain to the upper extremities (the musculoskeletal system) was scored before and after the training period with a self-designed questionnaire on a 5 point scale (with 1= not serious and 5 =very serious) (Van Drongelen et al., 2006). We scored shoulders, elbows and wrists separately, but the scores for left and right were summed. A questionnaire was also used to score possible other training and/or exercise-related complaints (not to the musculoskeletal system) on items such as abundant sweating, not being able to sweat, numb feeling, itchiness, too cold, too hot.

Statistical analyses

The change between the pre- and post-training outcome measures was examined using a two-tailed Students' paired t-tests ($p < 0.05$). In addition, for those subjects of the subgroup who completed the double baseline design, a paired t-test was performed to compare the differences between the changes in outcome measures over the training period (t2-t1) with the change over the preceding non-training control period (t1-t0) ($p < 0.05$).

RESULTS

Subjects

22 subjects were included in this training study (Table 1).

Table1: Subject characteristics, training compliance and results on PO_{peak} and VO_{2peak}

subject	gend	age	TSI	wght	lesion level	AIS	daily wch	phys act	HC-Exper	train period	compl ses	PO_{peak}		vo_{2peak}	
												pre	post	pre	post
	m/f	yr	yr	kg	l - r			hrs/wk		weeks		W		L/min	
1	m	41	15	83	C6 C6	B	el	0	no	10	17	28.8	38.8	1.12	1.38
2	m	22	2	86	C6 C7	B	hr	1,5	yes	8	24	51.8	65.0	1.60	1.93
3	m	37	15	85	C6 C6	B	hr	1,5	yes	8	23	74.3	78.5	1.6	2.02
4	f	31	17	58	C6 C7	C	hr	1	yes	8	23	41.8	53.8	1.21	1.57
5	f	37	20	65	C6 C6	D	el	0	no	8	20	14	16	0.95	0.95
6	m	64	3	88	C7 C7	B	el	0	yes	10	20	24	28	0.91	0.84
7	m	29	7	70	C6 C6	B	hr	1	yes	8	24	41.9	52.4	1.10	1.15
8	m	42	3	117	C6 C6	A	el	0	yes	*(3)*	*d-o*	*(32.0)*		*(0.82)*	
9	m	54	28	81	C7 C7	B	hr	1,5	yes	8	24	69.6	74.2	2.20	2.00
10	m	32	6	77	C7 C7	B	hr	1.5	yes	8	19	66.8	82.7	1.50	1.72
11	m	43	8	113	C5 C5	A	el	1.5	yes	6	13	16.0	16.0	0.91	1.04
12	m	32	12	80	C7 C8	A	hr	1	yes	7	18	66.6	86.0	1.73	1.87
13	m	28	6	84	C8 C8	B	hr	1	yes	8	19	60.6	71.7	1.40	1.66
14	m	44	2	71	C8 C8	D	hr	0	yes	7	17	47.1	57.6	1.69	1.39
15	f	48	6	70	C5 C7	B	both	1	yes	12	24	20.6	21.0	1.08	1.12
16	m	25	3	63	C5 C5	A	el	0.5	yes	8	20	14.0	22.0	0.75	0.81
17	m	48	12	100	C5 C6	B	hr	0.5	no	-	*d-o*	*(32.0)*		*(1.12)*	
18	f	58	20	84	C6 C6	B	el	0	no	*(5)*	*d-o*	*(23.7)*		*(0.94)*	
19	m	45	2	64	C8 Th1	B	hr	0	no	-	*d-o*	*(28)*		*(0.80)*	
20	m	34	3	77	C7 C7	B	hr	1	yes	-	*d-o*	*(36)*		*(1.32)*	
21	m	21	6	60	C5 C6	A	el	0.5	yes	*(10)*	*d-o*	*(16)*		*(0.61)*	
22	m	51	16	110	C6 Th1	A	hr	0	yes	-	*d-o*	*(17.8)*		*(0.90)*	
	mean	39	10	81						8	19	42.5	50.9	1.32	1.43
	Sd	12	7	17						1	3	21.9	25.4	0.40	0.43

Subj: subject, gend: gender, M: male, F: Female, TSI: Time since injury, wght: weight ,AIS: Asia Impairment Scale (Marino et al., 2003), Daily wch: daily wheelchair, hr: hand-rim wheelchair, el: electric wheelchair, Phys Act: physical activity, HC-exper: Hand cycle experience, compl. ses.: completed sessions, d-o: dropout, W=Watt

Five out of 22 subjects were moderately active (1.5 hours a week) and all other subjects were not or minimally physically active. 15 out of 22 subjects completed the training period (t1-t2): 8 subjects performed the pre- (t1) and post-training (t2) tests and 7 subjects (#1-7) also performed an additional control test (t0). Seven out of 22 subjects dropped out during the training period due to various reasons: problems with transportation to the training facility (#18), a chronic urinary tract infection (#19), persistent bowel problems combined with spasms (#20), pressure ulcers as a consequence of a fall out of the wheelchair at home (#21), work-related overuse injury to the elbow (#22), serious pain as a consequence of bowel problems (#17) and because of illness (the flu) after three weeks of training (#8). No significant differences were found in personal and lesion characteristics between the seven subjects who dropped-out (Table 1) and those who completed the training (n=15); age: 43±13 vs. 38 ± 11 yrs, TSI: 9 ± 7 vs. 10 ± 8 yrs, body mass: 87.4 ± 22.2 vs.78.2. ± 13.3 kg, number of subjects with lesion level: C5:2, C6:3, C7:1 and C8:1 (n=7) vs. C5:3, C6:6, C7:4 and C8:2 (n=15), number of subjects with AIS (Marino et al., 2003): A:3, B:4, C:0 and D:0 (n=7) vs. A:3, B:9, C:1 and D:1 (n=15), respectively. The differences between the dropouts and the subjects who completed the training in baseline-values for the main outcome measures PO_{peak} and VO_{2peak} were: 26.5± 7.2 W versus 42.5 ± 21.9 W (p=0.099) and 0.93 ± 0.25 versus 1.32±0.40 L/min (p=0.04). This suggests a somewhat better physical work capacity at baseline for the subjects that completed the training.

Training

Protocol

It turned out to be difficult for the subjects to complete 24 training sessions within the given period (Table1). The mean number of completed sessions for the training group (n=15) was 20 (± 3) and 5 subjects missed 5-7 sessions which is more than 20% of all training sessions. Main reasons reported for missing or postponing training sessions were: not feeling well because of an illness (urinary tract infection, flu), transportation problems, too busy (with work) or too tired, no persons available to help starting up training (especially for those with high tetraplegia who were training at home). Overuse injuries were not mentioned as reason for missing a training session although three subjects were advised once to postpone the training with one day and/or to train at a lower intensity (or gear) during the next session, to prevent the possible development of such overuse complaints.

The distances covered during the hand cycling training sessions improved over time and varied from 2-7 km. All subjects managed to train (n=15) between 60-80% HRR on average (with the 1-2 minute rest intervals included). During the 3-4 minute hand cycle intervals the HR was between 70-80% HRR. A mean intensity of 6 (±1) on the 10-point Borg-scale was reported after training compared to 7(±2) after completing the peak exercise test. Especially, subjects with a very limited active muscle mass and a high body mass, who were already exerting at a near maximal level when moving the hand cycle forward, had to use the hand cycle indoor trainer. The adjustable and low initial power level - possible with the use of an indoor trainer- allowed them to train within the anticipated intensity range during the initial phase of the training. After 4-6 weeks of training all subjects who completed the training were able to train outside at the suggested intensity (without the indoor trainer).

Adverse effects

The training (n=15) was never stopped because of pain complaints to the arms and/or shoulders. Comparing pre- and post-training (and within the double baseline group), no increase in subjective pain scores around wrists or elbows was found. Three subjects (# 3, 6 and 11) out of 15 reported a slightly higher shoulder pain score post-training compared to pre-training. All three mentioned that this was muscle soreness as a consequence of training too hard (with a (too) high gear setting) and the pain disappeared gradually within one day after training. From the questionnaire 'other experienced physical pain complaints' it appeared that three subjects (# 5, 6 and 14) felt substantially less cold below lesion level after the training period compared to baseline, which was regarded positive. Other than that, no differences were seen in severity of other complaints.

Outcomes

Hand cycle capacity

Table 2 presents the results of the pre-post-test outcomes (n=15).

Table 2: Results of the hand cycle training (n=15): paired t-test analysis of outcome measures pre- (t1) and post training (t2) (n =15).

		Pre-training t1	Post-training t2	Difference (t2-t1)	
Physical Capacity	*n*	*mean (sd)*	*mean (sd)*	*p-value*	*Mean (95 % CI)*
Hand cycle capacity					
PO_{peak} *(W)*	15	42.5 (21.9)	50.8 (25.4)	*<0.001*	8.3 (5.2 to 11.5)
VO_{2peak} *($ml\cdot min^{-1}$)*	15	1317 (399)	1431 (427)	*0.05*	114 (0 to 227)
VO_{2peak} *($ml\cdot kg^{-1}\cdot min^{-1}$)*	14	17.3 (5.2)	19.1 (5.7)	*0.03*	1.8 (0.2 to 3.4)
O_2P_{peak} *($ml\cdot beat^{-1}$)*	14	10.7 (2.8)	12.0 (4.0)	*0.06*	1.3 (0.1 to 2.5)
VE_{peak} *($L\cdot min^{-1}$)*	15	52.0 (17.3)	54.9 (19.2)	*0.15*	2.9 (-1.9 to 7.0)
RER_{peak}	15	1.10 (0.16)	1.10 (0.14)	*0.93*	0.01(-0.03 to 0.07)
$VO_{2submax}$ *($ml\cdot min^{-1}$)*	14	834 (116)	761 (58)	*0.04*	-73 (-3 to -144)
HR_{submax} *(bpm)*	14	92 (17)	88 (18)	*0.40*	-4 (-13 to 5)
HR_{rest} *(bpm)*	14	61 (13)	66 (13)	*0.04*	5 (0 to 10)
Vo_{2rest} *($ml\cdot min^{-1}$)*	14	347 (59)	345 (35)	*0.89*	-2 (-35 to 30)
Muscle strength (HHD)					
extension (L+R) *(N)*	8	331 (99)	321 (96)	*0.47*	-10 (-42 to 21)
flexion (L+R) *(N)*	15	571 (176)	578 (177)	*0.49*	7 (-14 to 27)
Endorotation (L+R) *(N)*	12	358 (130)	360 (118)	*0.83*	2 (-9 to 19)
exorotation (L+R) *(N)*	12	294 (101)	304 (98)	*0.10*	10 (-2 to 22)
abduction (L+R) *(N)*	15	336 (86)	355 (80)	*0.05*	19 (0 to 38)
Pulmonary function					
FVC *($L\cdot min^{-1}$)*	15	3.80 (1.24)	3.82 (1.21)	*0.80*	-0.02 (-0.21 to 0.16)
(%)	15	75.5 (15.4)	76.8 (17)	*0.45*	1.2 (-2.1 to 4.7)
PEF *($L\cdot min^{-1}$)*	15	6.52 (2.23)	6.14 (2.00)	*0.07*	-0.37 (-0.78 to0.04)
(%)	15	70.0 (21.3)	66.3 (18.9)	*0.27*	-3.7 (-8.2 to 0.8)
QOL SF-36					
General health *(%)*	14	74 (20)	77 (21)	*0.28*	3 (-3 to 11)
Mental health *(%)*	14	74 (13)	79 (9)	*0.10*	5 (-1 to 11)
Vitality *(%)*	14	65 (15)	69 (9)	*0.34*	4 (-4 to 12)

CI: confidence interval, PO_{peak}: peak power output, VO_{2peak}: Peak oxygen uptake, O_2P: peak oxygen pulse =, $VO_{2submax}$: sub maximal oxygen uptake, HR_{submax}: submaximal heart rate, HR_{rest}: rest Heart rate, Vo_{2rest}: rest oxygen uptake, RER: respiratory exchange ratio, VE: ventilation, HHD: Hand held dynamometry, QOL: Quality of life: % of maximal score. For some outcome measures of hand cycle capacity data was missing in one (but not the same) subject due to measurement errors. Muscle strength was not available in subjects for all muscle groups (as they scored less than 3 on MMT or not feasible due to pain).

Mean RER was 1.10 in both pre and post-test suggesting that, in general, peak capacity VO2 was reached. VO_{2peak} significantly improved on average 114 (±204) $ml\cdot min^{-1}$ after training which was an increase of 8.7 (±13.9) % (n=15; Table 2). Also, a significant improvement in PO_{peak} of 8.3 (±5.8) W was found after training, which was an increase of 20.2 (±15.0) %.

No significant improvement in O_2P:1.3 (±0.2) (p=0.06) was seen in the pre-post-training comparison (n=14; Table 2). As expected, HR_{peak} (n=14) did not change between pre- (128 (±24) b· min^{-1}) and post-training (127 (±27) b·min^{-1}). A significant decrease in sub maximal oxygen uptake during hand cycling of 73 ± 122 ml ·min^{-1} (8.8 ± (14.6) %) (p=0.04) was found (n=14; Table 2) at a constant power output, indicating an improved gross mechanical efficiency during hand cycling. No differences in VO_{2rest} were found due to training. In contrast, HR_{rest} appeared to be significantly higher after training in the pre-post group (n=14; Table 2)

Secondary outcomes

Of all arm muscle groups, only shoulder abduction strength improved significantly at the post-training measurement (5.6 (±11) %; table 2).
No effects of hand cycle training were found on pulmonary function outcome measures and on any of the health-related quality of life variables: general health, mental health and vitality.

Double baseline data

When comparing the change in outcomes between the training period and the control period in the small double baseline group (n=7), a significant improvement in VO_{2peak} (p=0.045) was found with +188 (± 200) ml·min^{-1} (15.5 (± 15.7) %) vs. 0 (± 164) ml·min^{-1} (0 (± 13.8) %). No significant improvement in PO_{peak} (p=0.06) was found after training: +8.0 (± 4.5) W (20.3 (± 11.4) %) as compared to +2.7 (± 5.7) W (7.0 (± 14.9) %) for the control period. No training effects in O_2P, HR_{peak} or $VO_{2submax}$ were found when controlling for difference over the baseline period. A significant difference in HR_{rest} was found: +8 (± 9) beats·min^{-1} over the training period compared to -6 (± 6) beats·min^{-1} (p=0.004) over the double baseline period. Small but significant improvements were found in shoulder exorotation: 4.3 (± 2.7) % vs. -3.3 (± 4.3) % and elbow flexion: 4.2 (± 4.7) % vs. -1.8 (± 3.3) % in the respective training and double baseline periods.

DISCUSSION

Structured hand cycle interval training showed significant positive effects on the primary outcomes of physical capacity (PO_{peak}, VO_{2peak}). On the majority of the other outcome measures, no significant effects were found. As is demonstrated in the current study, people with tetraplegia can improve their physical work capacity in a structured way, but the relatively high number of drop-outs and missed training sessions show that maintaining the training schedule is difficult in this group.

Training

We aimed at including untrained subjects with tetraplegia and encountered a relatively high dropout of approximately 30%. It appeared that the dropouts had a lower physical capacity at baseline compared to the subjects who completed the training period. The low physical capacity in the dropouts may have been a result of a (long) history of health problems that prevented them from maintaining their fitness level. Furthermore, persons with a relatively low physical capacity, regardless of lesion level, may be more vulnerable and thus more prone to develop health problems. On the other hand, health problems, although less severe, were also responsible for the high non-compliance rate found in the subjects who were training. It should be noted that health problems in both dropouts and training subjects were not related to the training. Therefore, (untrained) people with tetraplegia are vulnerable (Ginis and Hicks, 2005) and health-problems are likely to interfere with their life and thus also during a training period.

Protocol

From a preceding pilot project in untrained subjects with tetraplegia, interval training appeared to be more suitable than continuous aerobic training; Most of our pilot-subjects were not able to hand cycle continuously for more than approximately 5-7 minutes whereas several hand cycle blocks of 3 minutes, with rest in between, were well sustainable. Based on observation, subjects really needed the rest periods between the bouts of hand cycling in order to prevent extreme muscle fatigue and to delay muscle soreness. Therefore an interval-training (and discontinuous test) protocol was designed, which evidently allowed more people with tetraplegia to start and maintain the training scheme, even those with a very limited fitness at the start. Of all subjects entering the study (n=22), those who successfully completed the training (n=15) were able to train within 60-80%HRR, although some only with an indoor trainer during the first weeks of training. This intensity is within the range of 50-90% HRR, HR_{peak} and PO_{peak} imposed in previous upper body training studies in persons with tetraplegia (Valent et al., 2007a). The broad range (60-80%HRR) accounts for the variety in intensity common during interval-training, but also for the extremely low HRR as a consequence of the disturbed innervation of the heart resulting in a low HR_{peak} in persons with tetraplegia (Valent et al., 2007b).

Adverse effects

In about 40% of the subjects, light to moderate pain to the upper extremities was already present before they were included, although this never involved serious pain. Pain to the upper extremities, especially to the shoulder, is common in persons with tetraplegia with a prevalence between 40-70% (Curtis et al., 1999; Van Drongelen et al., 2006). Moreover, they are at higher risk of developing musculoskeletal pain as a consequence of partial paralysis of thoraco-humeral muscles and imbalance in shoulder muscles (Curtis et al., 1999). In this study, shoulder pain involved soreness to muscles around the shoulders and it appeared to be a temporarily consequence of training. In addition, we noticed that two out of three subjects with shoulder complaints (#2 and 3) were the only subjects out of 22 who were using conventional straight cranks (with a high positioned crank axis). They were forced to move their arms (further) against gravity above shoulder level, which may be disadvantageous for the shoulders. In training studies executed with arm cranking in subjects with tetraplegia the pedal axis was aligned with the midpoint of the subject's sternum (McLean and Skinner, 1995) or with shoulder level (DiCarlo, 1988), while (except for these two subjects) in the current study the highest position was at or below shoulder level.

We believe that hand cycling with a well-adjusted hand cycle offers a suitable mode of exercise, although the risk of over-use injuries is always present in persons with tetraplegia when being active. Especially untrained subjects with complete tetraplegia (with a low active muscle mass) may be extra prone to injuries to muscles and tendons. For example, we saw that, despite instructions, our subjects tended to cycle with high(er) gears instead of high(er) pedal frequencies. Cycling at a high gear may be a potential overload for the musculoskeletal system but is not reflected by exercise intensity (HRR). Therefore, especially in the first weeks of training, supervision is recommended.

Outcomes

Hand cycle capacity

The primary outcome measures in the study, PO_{peak} and VO_{2peak}, showed significant improvements over the training period. In the current study we also controlled for possible natural variations over time and test-learning effects for a subgroup. The training effects found on our primary outcome measures were uphold in the double baseline subgroup. Although some effects on secondary outcome measures were not confirmed. For example, our submaximal oxygen uptake improved according to the pre-post test design, which was in agreement with Mukherjee et al.(2001). However, when analyzing the double-baseline subgroup no effect was found.

Table 1 shows the large inter-individual differences in our main outcomes and clearly an improvement of 8 W after training is more substantial for someone with a baseline-value of 16 W than for someone with a baseline of 60 W. Moreover, it is difficult to compare absolute gains in PO_{peak} and VO_{2peak} with literature when different test devices and protocols have been used and with subject with different training status (Valent et al., 2007a). The relative gains of 20.2% in PO_{peak} and 8.7% in VO_{2peak} in the present study were in agreement with McLean and Skinner (1995), who found gains of 13.7% and 8.3% respectively. Their untrained subjects with tetraplegia were arm crank exercising at an intensity of 60% of PO_{peak}, 3 times weekly for 10 weeks. In another study on arm crank exercise in young persons with tetraplegia, gains were found of 23.8% in PO_{peak} and 99% in VO_{2peak} (DiCarlo, 1988) Cooney and Walker (1986) trained 5 subjects with tetraplegia (and 5 with paraplegia) and found gains in PO_{peak} and VO_{2peak} of 57 and 30% respectively. Their subjects, with unknown training status, performed circuit resistance training, 30 a 40 minutes 3 times weekly for 9 weeks. Dallmeijer et al.(1997) did not find any significant improvements in PO_{peak} and VO_{2peak} after quad rugby training.

However, this study involved only one training session a week. During clinical rehabilitation, Hjeltnes and Walberg-Henriksson (1998) found significant gains in PO_{peak} but no improvements in VO_{2peak}.

The question remains how much improvement is clinically relevant. According to Brehm et al (2004), 10% is considered to be a meaningful change and therefore the improvement in PO_{peak} in the current study is designated clinically relevant and the change in VO_{2peak} as near to clinically relevant.

The gains in work capacity express the ability to improve fitness in those with tetraplegia. The effects of hand cycle training will probably be primarily local and not necessarily central, given the extremely low muscle mass that is actively involved in the exercise in this population (Glaser, 1989). The greater relative increase (20.2%) in PO_{peak} (as compared to VO_{2peak} (8.7%), indicates an improvement in gross mechanical efficiency (De Groot et al., 2002), i.e. effects in (reduced co-contraction as part of) muscle coordination of the arms and shoulders, as well as in the external force production.

Muscle strength

We only found some minor (borderline) significant improvements in muscle strength (shoulder abduction, elbow flexion and shoulder exorotation) after hand cycling, which were not considered clinically relevant. In general however, subjects reported to feel stronger. A possible explanation may be that muscle endurance has improved but not isometric peak strength (which we had measured).

Pulmonary function

We did not find any improvements in FVC or PEF. From literature however, it appears that the effects of upper body training on pulmonary function in persons with high paraplegia and tetraplegia are not uniform (Crane et al., 1994; Gass et al., 1980; Valent et al., 2007a).

Quality of life

Probably, the small sample size as well as the short period of training in the current study hampered a functional change in health-related quality of life as a possible consequence of increased fitness. Hicks et al (2003) found a significant improvement on quality of life after nine months of exercise training compared to a randomised control group, which however is a considerably longer training period compared to the current study. A significant association is assumed between physical fitness and outcomes on quality of life, well-being and participation (Noreau and Shephard, 1995).

HR_{rest}

Although HR_{rest} was not an intended outcome of the current study, it is interesting to note that a consistent increase in HR_{rest} was found after training, which is in agreement with previous training studies in subjects with tetraplegia (McLean and Skinner, 1995; Phillips et al., 1989). In untrained individuals without SCI, a decrease in HR_{rest} can be expected as a consequence of aerobic training (Wilmore et al., 2001). The higher HR_{rest} may have been the result of a central adaptation to the hormonal system induced by training, resulting in an increase in sympathetic drive or a decrease in parasympathetic tone (Phillips et al., 1989). This adaptation may have been triggered by an increase in the resting metabolic rate, resulting in an increased blood circulation, reflected by a higher HR_{rest}. The fact that some subjects reported to feel less cold during the day, since they were hand cycle training is in line with this. On the other hand, we did not find an increase in VO_{2rest} to support this hypothesis. Finally, a higher HR_{rest} due to overtraining did not seem likely when taking into account the unchanged scores on vitality (e.g. fatigue and exhaustion).

Study limitations

The most optimal study design (a RCT) was not feasible due to the small number of available subjects. Another limitation is the variability in (baseline) physical capacity between subjects. However, coalescing subgroups to reduce variability is hampered by the small sample size.

The number of drop-outs and non-compliance due to circumstances is considerable, but not uncommon in training studies in persons with tetraplegia (Valent et al., 2007a). Due to dropouts, the subject group serving as their own controls (n=7) was small to perform statistical analysis of a double baseline group.

Our subjects trained less than the planned number of training sessions (which may have had a negative effect on the results) but nevertheless, an effect was found on the primary outcomes of physical capacity.

Recommendations

When prescribing a hand cycle training program for vulnerable persons with tetraplegia, an interval-training protocol at 60-80%HRR (8-12 weeks, 2-3 sessions a week) appears appropriate to prevent the occurrence of serious muscle fatigue and over-use injuries. Depending on the activity level in the preceding period and the abilities of the individual with tetraplegia, the training frequency and intensity should be adjusted and build up gradually, preferably over a longer period. It may be worth considering starting hand cycle training already during (early) rehabilitation as part of a healthy active lifestyle program to learn and accommodate individuals to the importance of exercise and to learn to cope with the personal and practical barriers in an early stage. Training after conclusion of rehabilitation and under the supervision of the rehabilitation center or other local specialized personal can help maintain motivation and prevent and/or reduce personal barriers.

The literature on upper body training effects in subjects with SCI really lacks sufficient attention to those with tetraplegia (Valent et al., 2007a). Therefore, future research should focus on the optimization of training protocols specifically designed for persons with tetraplegia and on the ergonomic design of the hand cycle in those individuals.

In conclusion

Taking into account the dropouts in the current study, hand cycle training in subjects with tetraplegia is most likely to be successful in those with a relatively higher baseline physical capacity. However, also subjects who were training appeared to be vulnerable due to health reasons. In spite of non-compliance, the training subjects were able to improve their physical capacity, reflected by peak power output and oxygen uptake, even after a relatively short training period of 8-12 weeks. Marginal effects were found on muscle strength of the upper extremities and hand cycle efficiency. No effects of hand cycle training were found on pulmonary function and health-related quality of life. Larger study groups are required here. Finally, due to training all subjects were able to hand cycle distances outside, indicating the potential of the hand cycle for daily ambulation as well as for a physically active lifestyle.

Acknowledgements
We thank the Netherlands Organisation for Health, Research and Development ZON-MW who supported this study (grant number: 014-32-012), in The Hague.
Furthermore, we thank all subjects for their enthusiastic participation and the trainers in the rehabilitation centers Heliomare, RCA and the Hoogstraat for their help with the training sessions.

Appendix 1

Training protocol:

Week1	***Week2***	***Week3***	***Week4***	***Week5***	***Week6***
3 min hc *2 min rest* 6x	*3 min hc* *2 min rest* 7x	*3 min hc* *1.5 min rest* 7x	*3 min hc* *1.5 min rest* 8 x	*3 min hc* *1.5 min rest* 8x	*3 min hc* *1 min rest* 8x
Week7	***Week8***	***Week9***	***Week10***	***Week11***	***Week12***
3 min hc *1 min rest* *8x*	*4 min hc* *1.5 min rest* *7x*	*4 min hc* *1.5 min rest* *7x*	*4 min hc* *1 min rest* *7x*	*4 min hc* *1 min rest* *7x*	*4 min hc* 1 min rest *8x*

Figure 1: Hand cycle test