

## **Chapter 7**

### **General discussion**



## Discussion

### ***Upper body training in persons with SCI***

The aim of the current thesis was to investigate the effects of hand cycling on physical capacity and health in persons with SCI during and after rehabilitation. Before the main findings will be discussed, a state of the art of literature on the effects of upper body training on physical capacity is presented. Regular exercise in persons with SCI is considered to be beneficial for overall fitness (Devillard et al., 2007; Figoni, 1990; Glaser, 1989; Noreau and Shephard, 1995; Rimaud et al., 2005). Based on the review in Chapter 2 and the recent review by Fernhall et al. (2008) it is concluded however that, due to the limited number of studies, the small and heterogeneous subject groups and the low methodological quality of the studies (with hardly any randomized controlled trials: RCTs), the evidence in literature is not strong. It was not possible in the review of Chapter 2 to compare the effects on physical capacity between specific training modes, especially not during clinical rehabilitation. The lack of control groups (receiving usual care or no training) but also differences in training protocols and training periods hinder comparison between available studies.

Persons with paraplegia and tetraplegia are expected to benefit from training and although the absolute gains in physical capacity may be larger in persons with paraplegia (Jacobs and Nash, 2004), the relative gains compared with baseline, are considered to be comparable. In persons with a chronic paraplegia the improvements were between 10 and 30% for  $PO_{peak}$  and  $VO_{2peak}$ . The number of studies on persons with tetraplegia however was too small to draw conclusions on relative gain (Chapter 2). The most commonly used training modes were arm crank exercise, wheelchair exercise and circuit resistance training. Studies on the effects of hand cycle training on  $PO_{peak}$  and  $VO_{2peak}$  were previously not available and thus not included in the review of Chapter 2.

Compared to the conventional training options, hand cycling is considered to be an appropriate mode of training for persons with SCI: i.e. more efficient and mechanically less straining compared to hand rim propulsion. Therefore, in current study the objective was to investigate the effects of hand cycle training

compared with no hand cycle training, in persons with SCI during and after the clinical rehabilitation period. Special attention was given to those with cervical lesions as less is known about the effects of exercise in this group with physiological and cardiovascular mechanisms that deviate from generally patterns (Figoni, 1993; Hjeltnes et al., 1998). In addition, the need for regular well-adjusted exercise is suggested to be even more important in this fragile population.

### **Effects of hand cycling**

Three studies were performed on the effects of hand cycling in persons with SCI: an epidemiological study during and (shortly) after clinical rehabilitation (Chapter 3), an experimental study in the post-clinical rehabilitation period in subjects with tetraplegia (Chapter 5) and an experimental study in the clinical period (Chapter 6).

#### *Main outcomes: $PO_{peak}$ and $VO_{2peak}$*

The results of the epidemiological study (Chapter 3: (Valent et al., 2008)) showed significant gains in hand rim wheelchair capacity (reflected by  $PO_{peak}$  and  $VO_{2peak}$ ) in persons who hand cycle regularly during rehabilitation compared to non-hand cycle users. These results were however only found in those with paraplegia and not in persons with tetraplegia. The latter group was however smaller and more heterogeneous. In the (quasi) experimental hand cycle training study that was performed during clinical rehabilitation (Chapter 6), trends in improvements of wheelchair capacity for  $PO_{peak}$  and oxygen pulse, but not for  $VO_{2peak}$ , were found for persons who received additional hand cycle training compared to matched controls receiving usual treatment. Improvements for  $PO_{peak}$  and  $VO_{2peak}$  were however found in the experimental and control group.

The trend of improvement may be explained, among others, by the heterogeneity of the SCI-group (with all lesion levels) and the variation in duration of training. Comparison with previous upper body training studies during clinical rehabilitation is hampered because, in contrast to the current study, only pre-post-training designs were used.

After clinical rehabilitation (Chapter 5), the subjects with chronic tetraplegia improved significantly on  $PO_{peak}$  and  $VO_{2peak}$ , as determined in a hand cycle

exercise test. The subgroup in which effects of a preceding non-training period were compared with the hand cycle training period, showed similar positive results. Comparison of the effects of hand cycling with the few other upper body training studies in persons with chronic tetraplegia (Cooney and Walker, 1986; Dallmeijer et al., 1997; DiCarlo, 1988; McLean and Skinner, 1995) is again difficult in the post-clinical rehabilitation period, mainly due to different training protocols and training status. The findings however seem in agreement with the arm crank training study of Mc Lean and Skinner (1995).

All three studies combined, mostly positive effects were found for  $PO_{peak}$  and  $VO_{2peak}$  following hand cycling, as can be seen in Table 1. Nonetheless, in the experimental study during the clinical rehabilitation period (Chapter 6) only trends of improvement were reported whereas more clear improvements were reported in the post-clinical experimental subjects (Chapter 5).

It is interesting to discuss these results in relation to the phase of rehabilitation: the clinical or post-clinical rehabilitation period. During early rehabilitation, subjects are generally unstable and prone to over-use injuries and other complications, which may limit trainability, especially after a bed-bound period, while at the same time natural recovery may occur. During the post-clinical rehabilitation period, persons with SCI are generally more stable, although especially those with tetraplegia may remain more prone to health complications as is explained in the introductory chapter and appeared from Chapter 5. In all three studies, subjects were vulnerable because they were in the clinical rehabilitation phase or because they were persons with tetraplegia. As a consequence of the vulnerability (resulting in non-compliance), gains were expected to be low. On the other hand, in all three studies subjects were untrained and were expected to profit from training. Especially training with a hand cycle, offers a suitable exercise mode to gradually improve physical capacity.

In addition, a possible explanation why persons of the epidemiological study (Chapter 3) who were hand cycling regularly in the first year after discharge, did not improve (Table 1), was that most of them were already well trained on hand cycling during rehabilitation. Not much gain could be expected unless the frequency and intensity of hand cycling would have been markedly increased, which did not occur. Structured hand cycle training in persons with a

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longstanding (cervical) lesion did however result in significant improvements in  $PO_{peak}$  and  $VO_{2peak}$ , as is shown in Table 1 (Chapter 5). It was assumed that (especially untrained) subjects with longstanding paraplegia (not investigated in the current thesis) would show positive and probably more homogeneous results than the subjects with chronic tetraplegia following structured hand cycle training. In addition, we did see clear improvements in the homogenous group of subjects with paraplegia during clinical rehabilitation in the epidemiological study of Chapter 3, Table 1.

Furthermore, in comparison with the training study during rehabilitation (Chapter 6), the training set-up in the post-clinical rehabilitation study (Chapter 5) was more standardized (with a fixed number of training sessions). Finally, during the clinical rehabilitation period the contrast between the training and control group (both receiving a considerable amount of physical training) is assumed to be considerably smaller than the contrast between the training and control group in the post-rehabilitation period. Therefore, it is less likely to find positive training effects in the clinical rehabilitation period.

**Table 1: The effects of hand cycling on the main outcome measures**

	Physical capacity				Muscle strength		Pulmonary function		Health-QOL	Over-use injuries upper extremities
	$PO_{peak}$		$VO_{2peak}$		EE,EF, EX,EN, AB,		- FVC (%) - PEF		-General h. - Mental h. - Vitality	
	TP	PP	TP	PP	TP	PP	TP	PP	P=	
	P=	P=	P=	P=			P=	P=	P=	yes/no
epidem. study clin rehab (ch3)	0.35 <sup>wc</sup>	<b>0.00<sup>wc</sup></b>	0.32 <sup>wc</sup>	<b>0.00<sup>wc</sup></b>	-	<b>EE</b>	0.88 0.39	0.90 0.51	NA	NA
post clin rehab (ch3)	NA	0.92 <sup>wc</sup>	NA	0.89 <sup>wc</sup>	NA	<b>EE</b>	NA	0.23 0.37	NA	NA
Quasi exp. studies clin rehab (ch6)	0.08 <sup>wc</sup> <b>0.00<sup>hc</sup> nC</b>		0.36 <sup>wc</sup> 0.07 <sup>hc</sup> nC		<b>ENDO, EXO EF (left)</b>		0.62 0.72		NA	no
post clin rehab (ch5)	<b>0.00<sup>hc</sup> nC</b> 0.06 <sup>hc</sup>	NA	<b>0.05<sup>hc</sup> nC</b> <b>0.05<sup>hc</sup></b>	NA	<b>AB</b>	NA	0.45 0.27	NA NA	0.28 0.10 0.33	no

*Epidem: Epidemiological, Exp: Experimental, rehab: rehabilitation, Health-QOL: health-related quality of life, p: p-value is bold when significant, Muscle groups are bold with significant positive effects of hand cycling. EE: elbow extension, EF: elbow flexion, EXO: shoulder exo-rotation, ENDO: shoulder endo-rotation, AB: shoulder abduction, TP: tetraplegia, PP: paraplegia, NA: not available or no statistical analysis possible due to small sample size, <sup>wc</sup>: wheelchair exercise test, <sup>hc</sup>: hand cycle exercise test, nC: no comparison with control group (usual care)*

*Other outcomes*

Besides wheelchair and hand cycle capacity, secondary outcomes such as muscle strength and pulmonary function were evaluated. One might expect both elbow extension (m. triceps) and flexion (m. biceps) to improve, as they are important muscles involved in the respective push and pull movement during hand cycling (De Coster et al., 1999). In the epidemiological study (Chapter 3) a relationship was found between regular hand cycle use and elbow extension strength in persons with paraplegia during and after clinical rehabilitation, but no relationship was found with any of the other studied muscle groups (elbow flexion strength, shoulder abduction and -endorotation or – exorotation). In persons with tetraplegia none such relationships were found. This may be explained by the fact that the measurement of muscle strength was not possible of all muscle groups of the subjects with tetraplegia; e.g. strength during extension of the m. triceps since this function is absent in persons with motor complete cervical lesions C5 or C6. This implies that the already small and heterogeneous group of persons with tetraplegia became even smaller. The same applied to the experimental subjects in the post-clinical rehabilitation period in Chapter 5 in which we found marginal effects on shoulder abduction, shoulder exorotation and elbow flexion strength, but no effects on elbow extension strength. In Chapter 6 we found positive effects on shoulder endorotation and exorotation strength and unilateral elbow flexion strength after structured hand cycle training, in comparison to matched controls.

In conclusion, in all three studies some statistically significant improvements in arm strength as a result of hand cycling were found. The improvements were not very consistent as they were reported in different muscle groups (Table 1). It is important to state however, that subjects were trained primarily to build up aerobic capacity/ fitness and functionally to be able to cover distances outdoors and not specifically to increase muscle strength. Strength training studies in persons with paraplegia (Jacobs et al., 2002b; 2001; Nash et al., 2001; 2002; 2007) support the view that specific protocols may lead to more outspoken peak strength improvements after hand cycle training. Furthermore, based on personal observation, possibly not peak muscle strength, which was measured in the present studies, but muscle endurance may be improved after hand cycle training. A better wheelchair or hand cycle exercise test performance may also

be the result of local muscle adaptations, resulting in an improved muscle endurance (Harvey, 2008).

Another secondary outcome of physical capacity, which we have evaluated, is pulmonary function, which is affected in persons with high paraplegia or tetraplegia. The pulmonary function of these persons is expected to benefit most from exercise training (Crane et al., 1994). Pulmonary function improved during clinical rehabilitation (Chapters 3 and 6) which is in agreement with the study of Mueller et al. (2008) but these improvements of pulmonary function could not be attributed to hand cycling alone (Table 1). In contrast, we did not find significant pre-post hand cycle training effects on pulmonary function in persons with chronic tetraplegia after clinical rehabilitation (Chapter 5). These findings were in agreement with previous aerobic upper body training studies (Taylor et al., 1986; Valent et al., 2007a; Yim, 1993). Significant and clinically relevant improvements, defined as >10% (Brehm et al., 2004) in pulmonary function as a result of aerobic training are not commonly found in persons with a longstanding SCI.

Health-related quality of life did not change significantly, most likely due to the short training period of 8-12 weeks but also due to the small subject group in combination with lack of responsiveness of the outcome measures (questionnaires) in Chapter 5. Indeed, Hicks et al. (2003) found a significant improvement on quality of life after a considerably longer period of nine months of upper body training. After a few weeks of training, experimental subjects of both studies described in Chapters 5 and 6 appeared to be able to hand cycle distances outside. Most of them enjoyed the training sessions, in particular those who were training in a group. The long distances covered outdoors, even by subjects with tetraplegia (Janssen et al., 2001), indicate the potential of the hand cycle for daily ambulation and thus a more physically active lifestyle. It has been concluded by several authors (Giacobbi, 2008; Manns and Chad, 1999; Tasiemski et al., 2005) that fitter and more active persons with SCI perceived themselves as less 'handicapped' than their inactive peers, while lower levels of participation are a significant predictor of depression (Tate et al., 1994) but this was not investigated in the present thesis. However, a larger subject group performing hand cycle training for a longer period is expected to show a positive effect on quality of life.

As stated already in the introductory chapter, quality of life is closely associated with a higher degree of independent living and participation (Noreau and Shephard, 1995). When integrated in daily life on a regular basis as exercise and/or transportation mode, hand cycling may eventually improve the level of independent living, social participation and quality of life.

### ***Hand cycle training***

In the current thesis, subjects were generally untrained and - especially in early phase of rehabilitation - inexperienced in hand cycling. As suggested by Hjeltnes et al. (1986) and in the introductory chapter of current thesis, arm cranking (and also hand cycling) seems to be an unskilled task, which should be recommended early after injury for endurance training rather than wheelchair training. Compared to hand rim wheelchair exercise, a larger and more balanced muscle mass is involved, assumingly at a lower mechanical load, which makes it a safe mode of exercise for untrained vulnerable persons with SCI.

An interval-training protocol was used as this was found to be extremely suitable for persons with a low physical capacity (Butcher and Jones, 2006; Tordi et al., 2001; 1998), From a pilot study it was seen that untrained subjects with tetraplegia had to stop already after only a few minutes of continuous hand cycling as a consequence of extreme muscle fatigue. The small active muscle mass, imbalance in muscle group strength and the disturbed blood supply were factors assumed to contribute to this early muscle fatigue. Personal observations make clear that especially the untrained subjects with tetraplegia needed (short) rest periods in between short bouts of hand cycling. Also frequent periods of recovery are considered to reduce the repetitive strain on the musculoskeletal system and thus the occurrence of overuse injuries (Bonninger et al., 2005). Interval training (if sustainable) at a higher intensity but same total work load, has been shown to elicit greater physiological change than continuous aerobic training at a lower constant intensity (Butcher and Jones, 2006). All the subjects in the present studies with SCI and of different age, lesion levels and training status, were able to train satisfactory with the interval-training protocol (Chapter 5, Appendix 1).

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Training intensity can be imposed and monitored using different indicators: heart rate, oxygen uptake, power output, or through subjective indicators such as the score on a Borg-scale. The continuous monitoring of power output with a power measuring system, commonly used for cycling, may be very suitable in hand cycling as it allows training at percentage of peak power output (McLean et al., 1995). However, at the time of the experimental study (Chapter 4) the validity and reliability of power measuring systems (e.g. Powertap, Ergomo and SRM) commonly used for cycling (Bertucci et al., 2005; Paton and Hopkins, 2006), were not yet evaluated in low-intensity hand cycling. Measuring  $VO_2$ , although reliable, is not practical since it requires ambulant and expensive instrumentation. Therefore it was decided to use heart rate monitors together with a Borg-scale.

A training intensity of 60-80% heart rate reserve (HRR) was imposed in persons with chronic tetraplegia which was within the range of the guidelines for continuous exercise of the ACSM of able-bodied persons (Pollock, 1998) and previous upper body training studies in persons with SCI (Chapter 2) (Valent et al., 2007b). Several studies (Bar-On and Nene, 1990; Goosey-Tolfrey and Tolfrey, 2004; Hjeltnes, 1977; Hooker et al., 1993; Schmid et al., 1998; Tolfrey et al., 2001) showed strong individual linear HR- $VO_2$  relationships in those with paraplegia and consequently training on heart rate appeared to be valid for this group. The data on individuals with tetraplegia in Chapter 4 however, showed that a reliable linear relationship between HR and  $VO_2$  was found in half of the subjects with tetraplegia. The lack of a reliable relationship in the other half may be explained by the disturbed sympathetic innervation resulting in a restricted peak heart rate and an inadequate blood circulation. In agreement with Mc Lean et al. (1995), it is concluded that heart rate may not reflect the exercise intensity adequately in all persons with tetraplegia and those with high thoracic lesions (>Th5). Therefore, the individual HR- $VO_2$ -relationship should be investigated to evaluate the appropriateness of heart rate as indicator of exercise intensity. Possibly in future, with the standard evaluation of the autonomic nervous system in addition to the ASIA (Krassioukov et al., 2007) more knowledge will become available on the severity of autonomic dysfunction and its influence on the oxygen uptake -heart rate -relationship.

The complementary use of the easy applicable Borg-scale was previously recommended in persons with tetraplegia (McLean et al., 1995) and paraplegia (Grange et al., 2002). The present study however, showed some limitations of the Borg-scale in persons with tetraplegia who, in general, appeared to be more affected by local muscle fatigue, while the Borg-scale evaluates general perceived exertion. Based on their results also Lewis et al. (2007) concluded that the Borg-scale may not be a valid index of perceived exertion in persons with paraplegia or tetraplegia. Moreover they also emphasized the importance of discriminating peripheral from central cues when using the Borg-scale.

In conclusion, hand cycling is assumed to be a safe exercise mode and interval training is regarded a useful protocol to train physical capacity in persons with SCI. The actual training intensity in persons with SCI appears to be reasonably reflected by a large target heart rate range (60-80%HRR) together with a Borg-scale. Especially in persons with tetraplegia however, hand cycle training on basis of percentage peak power output must be seriously considered as an alternative.

### ***Hand cycle testing***

To test peak exercise capacity adequately in persons with SCI, especially with tetraplegia, several factors are important such as test mode (wheelchair propulsion, arm cranking or hand cycling) and test protocol (continuous/discontinuous and work rate increments).

The untrained to moderately trained subjects with tetraplegia scored relatively high  $VO_{2peak}$ -values during a discontinuous hand cycle exercise test:  $1.08 \pm 0.36 \text{ L}\cdot\text{min}^{-1}$  (Chapter 4) and pre- and post-training values of  $1.31 \pm 0.40$  and  $1.43 \pm 0.43 \text{ L}\cdot\text{min}^{-1}$  (Chapter 5) respectively. This is in agreement with Janssen et al. (2001) who also found higher values during hand cycle testing in subjects with tetraplegia than previously reported. Previous studies evaluating persons with chronic tetraplegia (of different training status) during peak wheelchair exercise (Coutts and McKenzie, 1995; Coutts et al., 1983; Dallmeijer et al., 1997; Gass et al., 1980; Janssen et al., 2002; Lasko-McCarthy and Davis, 1991; Schmid et al., 1998) and/or peak arm crank exercise (Goosey-Tolfrey et al., 2006; Hopman et al., 1998; 2004; Jacobs et al., 2002a; McLean and Skinner, 1995), reported substantially lower mean values ranging from 0.70-

1.03 L·min<sup>-1</sup> with the exception of the high post-training values in the arm crank study by Di Carlo (1988).

In general, personal (age, gender, rehabilitation and/or training status) and/or lesion characteristics (lesion level and completeness) may explain some of the variation in VO<sub>2peak</sub>-values. It is most likely however, that differences in A) test protocols (discontinuous/ continuous and work rate increments) and/or B) test modes (arm cranking, wheelchair or hand cycling) may be responsible for this variation.

A) Continuous and discontinuous arm work yielded comparable results in able-bodied subjects and persons with paraplegia (Rasche et al., 1993; Washburn and Seals, 1983). However, based on the physiology of persons with tetraplegia (Chapter 1) and the results of a pilot study in this particular group it was decided that a discontinuous protocol should be more appropriate to prevent the occurrence of local muscle fatigue and ability to continue the test. A protocol of 2 minutes hand cycling with 30 seconds recovery in between and small increments of 2-5 W (as was recommended by Lasko-McCarthy and Davis (1991)) was applied (Chapters 4 and 5). It was assumed that in persons with tetraplegia this protocol would lead to higher VO<sub>2peak</sub>-values than a continuous protocol.

B) An other factor that may be responsible for differences in VO<sub>2peak</sub> is the mode of testing: in the current thesis as well as in the only other study comparing hand cycle and wheelchair propulsion (Dallmeijer et al., 2004b), a hand cycle test yielded higher VO<sub>2peak</sub> and PO<sub>peak</sub>-values than the wheelchair test. In previous research comparing arm crank and wheelchair exercise in able-bodied subjects and subjects with paraplegia (Gass et al., 1995; Glaser et al., 1980a; Martel et al., 1991; McConnell et al., 1989; Sedlock et al., 1990; Wicks et al., 1983), most authors also reported higher values of peak power output in arm crank exercise than in wheelchair exercise but no differences in VO<sub>2peak</sub>. It is questionable however, whether results of previous arm crank exercise studies can be generalised towards today's hand cycling and more specifically to persons with tetraplegia. It is important to focus more closely on possible differences between arm crank exercise and modern hand cycling (when performed by persons with SCI and especially tetraplegia). At least two aspects of the difference between arm crank exercise and hand cycling seem to

be important: 1) the positioning of the crank axis (interfacing) and 2) the mode of cranking: asynchronous or synchronous.

1. In previous studies on arm crank exercise in tetraplegia the positioning of the crank axis was often mid-sternum (McLean and Skinner, 1995) or at shoulder level (DiCarlo, 1988; Goosey-Tolfrey et al., 2006; Hopman et al., 1998; 2004), whereas in modern hand cycling a trend is seen that the axis is positioned as low as possible which is allowed by the curved cranks (Figure 6, Chapter 1) and often just below the sternum. A lower positioning of the axis may result in a better (peak) exercise performance in persons with tetraplegia for whom it is very strenuous to push above shoulder level against gravity.
2. In contrast to modern hand cycling, arm crank exercise has generally been performed asynchronously. Several studies have been performed comparing asynchronous with synchronous arm crank exercise (Glaser et al., 1980b; Hopman et al., 1995; Marincek and Valencic, 1977; Mossberg et al., 1999) and hand cycling (Abel, 2003; Bafghi et al., 2008; Dallmeijer et al., 2004a; Goosey-Tolfrey and Sindall, 2007; Van der Woude et al., 2000; Van der Woude et al., 2007). The results are not uniform in arm crank exercise but in hand cycling all studies found higher levels of peak performance and efficiency in the synchronous mode. This corresponds with the general preference for synchronous hand cycling in sport (Janssen et al., 2001) and daily life (Valent et al., 2007c). An explanation may be that, in contrast to asynchronous hand cycling, no energy costs are needed during synchronous hand cycling to prevent steering movements of the crank set while transferring power into propulsion (Abel, 2003; Bafghi et al., 2008; Dallmeijer et al., 2004a; Van der Woude et al., 2007). Another advantage of synchronous hand cycling is a better trunk stability: during the push-phase the reaction forces are directed perpendicular to the back rest, while asynchronous hand cycling causes rotation of the trunk along a longitudinal axis when one arm is extended and the other one flexed (Bafghi et al., 2008). Therefore, in contrast to asynchronous hand cycling, upper body muscles do not need to be active to stabilise the trunk. This is especially favourable for persons with higher thoracic or cervical lesions who lack active trunk and

(partly) arm muscles. Subjects with tetraplegia in the current studies never complained of sideward trunk instability during synchronous hand cycling while this is often experienced in practise during asynchronous cranking. The only trunk stability problem that some subjects experienced was falling forward in the pull-phase, which we were able to solve with a belt around the thorax. In synchronous hand cycling, upper body muscles are apparently used more efficiently: less muscle activity is needed to prevent trunk instability and unwanted steering movements (Van der Woude et al., 2007). Moreover, depending on lesion level, active trunk muscles may contribute to the propulsion by moving the trunk forward and/or backward.

In conclusion, synchronously hand cycling with a relatively low crank axis seems to be more suitable for persons with tetraplegia than hand rim wheelchair propulsion or asynchronously arm crank exercise. Therefore, this favourable hand cycle motion and the discontinuous test protocol may explain the relatively high  $VO_{2peak}$  and  $PO_{peak}$  –values in this particular group. Future studies should corroborate these notions of an optimum hand cycle interface.

### ***Over-use injuries and hand cycling***

Especially persons with tetraplegia are at a higher risk of developing musculoskeletal pain as a consequence of physical activity. The (partial) paralysis of thoraco-humeral muscles and imbalance in shoulder muscles, may lead to potential overuse of functional muscles (and other tissue) (Curtis et al., 1999; Powers et al., 1994). Persons with tetraplegia generally report a relatively low level of daily activity together with a higher prevalence of shoulder pain (Curtis et al., 1999). From the current studies, hand cycling during or after clinical rehabilitation did not have adverse effects in persons with paraplegia or tetraplegia: no increased pain to the upper extremities as a consequence of hand cycling was found (Chapter 3, 5, 6). This is in agreement with a recent study that evaluated the effect of arm crank training on shoulder pain in subjects with SCI (Dyson-Hudson et al., 2007). As in the current study, the authors avoided potentially injurious positions such as extreme internal rotation and abduction as well as extreme flexion and extension and a hand position above shoulder level. Also in a study on arm crank exercise in subjects with tetraplegia

by (Klefbeck et al., 1996) the cranks were adjusted so the highest point of the hand grips was at shoulder level, which is according to guidelines on shoulder preservation (Bonninger et al., 2005; Requejo, 2008). The risk of over-use injuries however, is always present in this particularly vulnerable group and therefore hand cycling should be performed with an adequate ergonomic interface, gear ratio, propulsion technique as well as an adequate training intensity, frequency and/or duration.

In conclusion, it was found that hand cycling in a well-adjusted hand cycle and with an individually matched interval training protocol does not provoke any adverse effects in persons with tetraplegia during and after clinical rehabilitation.

### ***Trainability of persons with a low physical capacity***

It is notable that the dropout rate in the presented studies was substantial, not as a consequence of the training but mainly due to other health complications such as pressure sores and urinary tract infections. This indicates the vulnerable general condition of this specific group (Ginis and Hicks, 2005). The dropouts tended to have a lower physical capacity at the start of training. However, non-compliance due to aforementioned health complications also occurred in subjects who completed the training period. From the current thesis and from international literature it is clear that the high prevalence of secondary complications appears to have a large and negative influence on general fitness (Post et al., 1998). The problem is that due to the negative consequences (bed-bound period) of a medical complication, it is difficult to maintain regular physical fitness. If these persons succeed in attaining and maintaining a higher level of physical fitness, would this help to prevent or reduce the occurrence of secondary complications in the future (Haisma, 2008)? In other words: can the debilitating cycle in persons with a low physical capacity be interrupted or reversed?

In the introduction of this chapter we mentioned the deviating physiological and cardiovascular mechanisms in persons with tetraplegia (Figoni, 1993; Krassioukov and Claydon, 2006). The trainability of the central and peripheral cardiovascular system will be discussed in persons with tetraplegia:

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In previous studies in subjects with tetraplegia (DiCarlo, 1988; Hjeltnes and Wallberg-Henriksson, 1998; McLean and Skinner, 1995) and in the current thesis mostly positive effects on peak power output, but to a lesser extent on  $VO_{2peak}$ , were found (Table 1). According to Figoni (1993), Hoffman (1986), Hopman et al. (1998) no evidence is available to support the presence of central cardiovascular training effects from arm exercise. Nevertheless, we found a tendency of an improved oxygen pulse in persons with tetraplegia, suggesting a potential for central improvements. Moreover, it was concluded that subjects with tetraplegia attained relatively high  $VO_{2peak}$ -values during hand cycling. It remains unknown however, whether energy levels required for hand cycling are high enough to induce a central cardiovascular training effect in persons with tetraplegia. It is most likely that peripheral adaptations occurred such as an improved ability of muscles to extract oxygen or an increased muscle mass, as is supported by a study by Hopman et al. (1998). Harvey (2008) stated that the increased ability to extract oxygen is one of the key factors increasing  $VO_{2peak}$  in all persons with SCI. For example, due to changes in muscle metabolism (e.g. increase in mitochondria, improved glycogen storage and synthesis) and/or a higher density of capillaries, less lactic acid is accumulated resulting in a delayed onset of muscle fatigue (Harvey, 2008). Besides these adaptations, a training effect may be expressed in an improved technique (coordination) resulting in less co-contraction of muscles.

In the present study (Chapter 5) mostly untrained subjects were included. It is possible that the 8-12 weeks of training lead to more peripheral (muscle) training effects, whereas a longer training period may lead to increased muscle endurance and eventually to some additional central effects. This is explained by a long-term adaptation-process of the small active muscle mass to the imposed specific load; this process needs to be gradual to allow recovery and adaptation to the increasing load over time: e.g. from practise it is seen that endurance athletes with tetraplegia, who adopted regular training (with wheelchair or hand cycle) as a lifestyle, are able to improve physical performance over years. Besides peripheral (muscle) adaptations, possibly also some minor (but clinically relevant) adaptations to the central cardiovascular system have gradually occurred over these years but this hypothesis is not confirmed as no studies focussed on the long-term aerobic training effects.

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However, in a group of well-trained athletes with SCI, including persons with tetraplegia (Abel et al., 2003), the energy turn over during both hand cycling and (more straining) wheelchair racing were found to be high enough to induce cardiovascular training responses, comparable to able bodied persons, and probably to help prevent cardiovascular diseases (Paffenbarger et al., 1993). Unfortunately, studies on physical capacity in wheelchair athletes are mostly cross-sectional (comparing with inactive persons) while athletes and non-active controls are hardly ever followed over a long period (Shephard, 1988). Therefore, selection of the fittest in most published studies cannot be ruled out while it is interesting to know if both athletes and inactive persons with tetraplegia can benefit from long-term regular physical training and thus may be able to deal better with the strain of daily life.

It may take a lot of extra time and effort to turn the tide in those with the lowest physical capacity, especially during rehabilitation. The few subjects with tetraplegia, who trained hand cycling regularly during a long period of active rehabilitation, seemed to benefit with considerable gains at discharge (Chapter 6). A relatively long period of rehabilitation may be favourable for a higher degree of independence of persons with tetraplegia, as is supported by data by Post et al. (2005). On the other hand, a more recent study of Haisma et al. (2007) showed that a long period of rehabilitation was not associated with higher fitness levels: In the Dutch centres the duration of rehabilitation seems to be more determined by waiting time for arranging post-discharge facilities instead of reaching rehabilitation goals. Therefore, after reaching the basic rehabilitation goals, aerobic training (e.g. hand cycling) indeed should be continued until (and after) discharge to prevent deconditioning during the final - often 'waiting' phase of rehabilitation (Haisma et al., 2007). In a study by O' Neill and Maquire (2004) a high proportion of patients perceived sporting activity as beneficial for rehabilitation with increments in fitness, quality of life, confidence and social contact. In addition, after discharge, patients may face a less adapted environment and acquired skills may appear more strenuous and difficult to put in practice than it was during rehabilitation (Haisma, 2008). To conclude, hand cycle training in spinal cord injured persons with a low physical capacity, should focus on achieving physical fitness AND functional hand cycle use in the own environment to ensure a sufficiently high degree of

independence and participation. Nonetheless, this particular group appears to be at higher risk of health complications, which may seriously interrupt training programs.

### ***Limitations of the studies***

In the current thesis no randomized controlled trials (RCT) could be conducted due to the small and heterogeneous sample sizes available in the experimental settings, and complexities of daily practice. This seems to be a more general problem in research on persons with SCI (Ginis and Hicks, 2005). It was possible however to compare the hand cycling subjects with control subjects from the epidemiological study (Chapters 3 and 6). They were selected retrospectively and on matched characteristics. The use of a regular care control group would have been more optimal. In the experimental study of Chapter 5, effects of a hand cycle training period were compared with a non-training period. It may be stated that, in contrast to most previous upper body training studies in persons with SCI, an effort was made in the current thesis to compare with non-training control subjects with SCI.

The effects of hand cycle training would have been more outspoken when evaluated with a hand cycle test. The effect of training was evaluated with a wheelchair test (in Chapters 3 and 6) because of its relevance for daily life and because experimental and control subjects were familiar with hand rim wheelchair propulsion but not with hand cycling. Moreover, a positive effect of hand cycle training on wheelchair peak performance was hypothesized, based on studies that found a transfer from arm crank training effects to wheelchair performance (DiCarlo, 1988; Sedlock et al., 1988).

A training frequency of twice a week was considered to be feasible in the experimental study during clinical rehabilitation (Chapter 6). Due to (temporarily) health problems, the subjects were not able to attend all sessions. In the busy rehabilitation program it was not always possible to make up for a missed training, resulting in a lower actual training frequency than planned. Consequently, the contrast between the hand cycling and control group in this study was smaller than expected.

It is likely that a longer period of training in the experimental studies during (Chapter 6) and after clinical rehabilitation (Chapter 5) would have resulted in

larger gains in our primary and secondary outcomes. A longer training period however, may result in a higher drop-out and non-compliance of subjects with SCI due to complications (Davis et al., 1991; Hicks et al., 2003). This may be especially the case in (untrained and/or older) persons with tetraplegia who are often tormented by secondary complications.

### ***Clinical implications***

Hand cycling appears to be a safe mode of exercise and mobility to train physical capacity in persons with SCI. This applies especially to those with a low physical capacity: persons during clinical rehabilitation and those with tetraplegia.

From findings in literature (Butcher and Jones, 2006; Tordi et al., 2001) and from this thesis it can be concluded that interval test and training-protocols are very suitable to prevent the occurrence of early local muscle fatigue and soreness. The interval-protocol is expected to allow more people with tetraplegia to complete the training program.

To impose an adequate strain during hand cycle training, monitoring of intensity is important. For persons with tetraplegia, training at a percentage of  $PO_{peak}$  may be more suitable than training at percentage of HRR or Borg-scale. Recently, power measurement systems (the SRM-system) have been used in hand cycling in able-bodied subjects (Van der Woude et al., 2007) and in arm cranking in athletes with tetraplegia (Goosey-Tolfrey et al., 2006). During early clinical rehabilitation of persons with SCI and especially those with tetraplegia, it is important to start at a low intensity and to build up the training load gradually. In this phase, arm crank systems (or roller ergometers) are advised because it is possible to start with a very low initial power. It is important however that the axis of the crank set is positioned as low as possible and that the hands remain below shoulder level during the full cycle (Bonninger et al., 2005). To prepare adequately for future hand cycling a synchronous (instead of a asynchronous) mode should be installed. In persons with tetraplegia, it is recommended to start with a few hand cycle bouts (e.g. 5x1 minute within 30 minutes of rest) during early clinical rehabilitation. Subsequently, a gradual increase in duration and repetition of hand cycle bouts and training sessions can be allowed. Eventually, after approximately 2 months, the protocol described in Chapter 5 can be used

(Appendix 1). In addition, functional hand cycle use should be trained especially in subjects with tetraplegia to ensure continuation of safe and independent hand cycling in the own environment after rehabilitation.

In The Netherlands hand rim wheelchairs are often prescribed together with an add-on hand cycle unit for outdoor mobility in persons with SCI with lesion level C5/C6 and below. In their clinical practice guidelines (Bonninger et al., 2005), recommend powered mobility when wheelchair propulsion is too strenuous. A valuable addition to these guidelines should be the use of hand cycling for outdoor mobility instead of powered mobility as a physically less straining alternative for hand rim wheelchairs yet allowing daily exercise. From a health perspective, the use of powered wheelchairs should be prevented as it may deteriorate physical fitness, especially in persons who are not likely to exercise. If the strain imposed by the environment is high (e.g. hills) and/or the physical capacity is low, even after a training period, the hand cycle-unit may be equipped with an electric power support, e.g.<sup>1</sup>

Different coupling systems exist which make it possible to attach the hand cycle unit independently to the wheelchair. However for persons with a C5-lesion this may be too strenuous and therefore powered wheelchairs may appear to be the final solution, enabling independent in- and outdoor mobility and thus participation. Nonetheless, with a little help from others, those who are not entirely independent in use of the hand cycle as a mobility device may still benefit from hand cycling for sport and recreation.

Furthermore, individuals should be made familiar with all available exercise options and accessibility of facilities in the own environment (e.g. fitness, circuit resistance training, hand cycling, wheelchair racing, quad-rugby and swimming). In addition, hand cycling offers an opportunity to recreate or exercise with peers or with able-bodied friends or family members who like to (Nordic) walk, jog, skate or cycle. Although not investigated in the current thesis, being able to participate independently in physical (outdoor-) activities, with others or alone, is likely to have a positive effect on self-esteem and well-being (Giacobbi, 2008; Nash, 2005).

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<sup>1</sup> [www.speedy.de](http://www.speedy.de), [www.doubleperformance.nl](http://www.doubleperformance.nl)

Based on these arguments, it is a challenging task to motivate and help individuals with SCI to adopt a physically active lifestyle during clinical rehabilitation and remain physically active after clinical rehabilitation and thus to maintain a long-term physically and mentally healthy lifestyle (Ditor et al., 2003; Fernhall et al., 2008). As is suggested by the ACSM: "Exercise = medicine". Especially after a period of illness or due to the consequences of a complication, it is of utmost importance to regain physical fitness (through active mobility or exercise and sport) carefully and gradually.

### ***Future research***

There is a need for training studies with the highest possible methodological quality in the field of upper body training (e.g. hand rim wheelchair, arm cranking, hand cycling, circuit resistance training etc.) in persons with SCI. An urgent need for randomized controlled training studies on the effects of training exists for spinal cord injured persons with a low physical capacity during clinical rehabilitation, in untrained or older persons and especially those with tetraplegia. The focus should be on underlying mechanisms responsible for adaptations to training in these vulnerable groups.

A relatively long training period may be needed to find substantial training effects, although non-compliance and dropout may seriously limit results. Therefore, to ensure large subject groups, multi-center collaboration may be needed to reach sufficient statistical power.

In future research on hand cycling and other upper body training modes, the effects of different training protocols (e.g. form, intensity, frequency, duration) should be compared on outcomes of physical capacity in persons with SCI. Of particular interest are studies comparing training forms such as interval, endurance and strength training protocols or combinations (e.g. circuit resistance training).

Differences between exercise modes (wheelchair exercise, arm crank exercise, hand cycling and circuit resistance training) should be subject of study. The focus however, should not only be on the effects on physical capacity but certainly also on the occurrence of upper body over-use complaints when comparing different protocols or training modes.

## *Discussion*

Future research should focus on mechanical load and physiology during hand cycling and the effects of adjustments to the ergonomic hand cycle-user interface: e.g. based on observation, it is assumed that a low position of the crank axis is favourable for persons with tetraplegia but so far this has not been investigated. Eventually this should result in specific training guidelines for (un-) trained persons with different levels of SCI.

Furthermore, it would be interesting to study the effects of regular hand cycle use or training on the level of social participation and quality of life.

To conclude, future research is needed on early training interventions (e.g. hand cycling) and on protocols that ensure continuation of exercise after the clinical rehabilitation period, as part of a physically active, healthy lifestyle in persons with SCI.