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ORIGINAL ARTICLE

The effect of arm-crank exercise training on power output, spirometric and cardiac function and level of autonomy in persons with tetraplegia

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Abstract
Studies on the effects of exercise training in persons with cervical spinal cord injury (CSCI) are scarce. The aim of this study was to determine the effect of an 8-week stationary arm-crank exercise (ACE) training programme on the level of autonomy, exercise performance, pulmonary functional parameters and resting heart rate variability (HRV) in persons with CSCI. Quadriplegia Index of Function (QIF), arm-crank peak power output (Ppeak), spirometric variables, and HRV indices were measured before and after the training programme in a group of 11 persons with CSCI. ACE training increased Ppeak in both groups ($p < 0.05$), whereas maximum voluntary ventilation (MVV) and low frequency HRV (LF) improved only in the lower CSCI group ($p < 0.05$). Moreover, QIF and Ppeak were significantly correlated before ($r = 0.88$; $p < 0.01$) and after ($r = 0.86$; $p < 0.01$) the training period. However, no significant changes were found in the level of autonomy (QIF) as a result of the intervention. Therefore, stationary ACE training appears to be a feasible and effective method for aerobic exercise in persons with tetraplegia and a short-term intervention is able to significantly improve exercise capacity, cardiac autonomic regulation and respiratory muscle endurance, regardless of the absence of significant immediate changes in the level of autonomy.

Keywords: *Power output, QIF, HRV, spirometry, tetraplegia, exercise*

Highlights

- Even individuals with higher CSCI (C4-C5) are able to perform a regular arm-cranck exercise training program that improves their power output.
- Persons with lower-level CSCI (C6-C7) retain their ability to increase resting HRV and improve respiratory function in response to a period of arm-cranck exercise training.
- No significant changes were found in the level of autonomy (QIF) as a result of the intervention.

1. Introduction

Persons with spinal cord injuries (SCI) have a loss of motor function and a reduction in habitual physical activity that results in a more sedentary lifestyle (van den Berg-Emons et al., 2008), which in turn leads to further impairment of their physical capacity and functional independence. Their daily activities are not sufficiently intense to maintain a healthy level of physical fitness, putting them at greater risk of respiratory disease and cardiovascular (CV) morbidity and mortality than the able-bodied population (DeVivo, Black, & Stover, 1993). Actually, over the past decade CV disease has emerged as the leading cause of morbidity and mortality in persons with chronic SCI (Myers, Lee, & Kiratli, 2007).

Cervical injuries account for roughly half of all SCI (Stover, DeLisa, & Whiteneck, 1995). These injuries mostly result in tetraplegia, with impaired movement and reduced function of the four limbs, depending on the level and severity of the injury and the individual's functional ability. Reduced physical fitness and ability to perform specific tasks are also considered a barrier to autonomy in individuals with tetraplegia (van den Berg-Emons et al., 2008). So respiratory function is also affected by high level SCI. Expiration force and the ability to cough are also reduced, which

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may cause secretions to accumulate in the airways. Pulmonary parameters such as vital capacity (VC), forced vital capacity (FVC) and maximum voluntary ventilation (MVV) can drop to approximately 50% of predicted standard values (Rochester & Esau, 1994), with a risk that these parameters can be significantly reduced over time (Tow, Graves, & Carter, 2001).

It is generally agreed that persons with SCI can improve their cardiopulmonary fitness, physical work capacity and endurance by means of physical activity and regular training (Crane et al., 1994; Hicks et al., 2003, 2011; Martin Ginis et al., 2018). Myers et al. (2007) concluded that enhancing physical activity is an important component in strategies intended to reduce the incidence of CV disease in persons with SCI. In addition, increasing the endurance capacity of adults with SCI improves their functional abilities (Dallmeijer & van der Woude, 2001) and may help to almost normalize their pulmonary parameters (Bodin, Kreuter, Bake, & Olsen, 2003) and positively affects their quality of life (QoL) (Giacobbi, Stancil, Hardin, & Bryant, 2008; Stevens, Caputo, Fuller, & Morgan, 2008).

Heart rate (HR) variability (HRV) analysis has become a widely-used non-invasive tool to quantify the autonomic control of heart rate dynamics (Task Force, 1996). Decreased variance around adjacent cardiac cycles at rest, especially when it is accompanied by elevated HR, has been proposed as a predictor for heightened risk of CV morbidity and mortality in individuals with SCI (Rosado-Rivera et al., 2011). HR response to vagal stimulation has been reported to be impaired in persons with tetraplegia (Claydon & Krassioukov, 2008; Wecht, Weir, & Bauman, 2006) and some authors have attributed lower HRV among individuals with SCI to a loss of low-frequency (LF) oscillations (Bunten, Warner, Brunnemann, & Segal, 1998). Little research, however, has been conducted on the effects of physical exercise programmes on HRV in persons with SCI. Exercise in these individuals is associated with abnormal CV control, which is related to the level and severity of injury to descending sympathetic pathways (Claydon & Krassioukov, 2008). A 6-month programme of thrice-weekly body weight-supported treadmill training (BWSTT) led to a significant reduction in the low-to-high frequency (LF/HF) ratio, corresponding to a significant reduction in LF power and no change in HF power (Ditor, Kamath, et al., 2005). However, a similar 4-month BWSTT programme failed to induce any changes in HRV (Ditor, Macdonald, et al., 2005). More recently, Millar et al. (2009) compared the effects of 4 weeks of thrice-weekly BWSTT versus passive head-up tilt training (HUTT). They found that BWSTT improved cardiac autonomic regulation but this change was only detected when HR dynamics were analyzed using nonlinear methods.

Handcycling based on arm-crank exercise (ACE) can be regarded not only as a very attractive competition sport (in the Paralympic Games held in Beijing in 2008 the handcycling competition was firstly included in the cycling events, Union Cycliste Internationale, 2019) and a valuable mobility mode in everyday life, but also as a very useful activity in rehabilitation, especially to improve endurance and functional abilities in people with severe physical impairment (Dallmeijer, Zentgraaff, Zijp, & van der Woude, 2004), and to enhance or maintain adequate fitness levels in persons with tetraplegia (Valent et al., 2009). The advantage of ACE compared to standard wheelchair propulsion is that ACE is more efficient and shoulder load is reduced, thus minimizing injury risk (Dallmeijer et al., 2004). Besides, it is preferable for long distances since the best gear ratio can be selected for each situation; in contrast, the wheelchair handrim diameter is very specific for a reduced range of speeds for persons with tetraplegia (Costa, Rubio, Belloch, & Soriano, 2009).

In this context, stationary ACE could be an effective exercise to improve both physical capacity and quality of life in persons with SCI (Hicks et al., 2003), as well as their pulmonary and CV function (de Groot, Hjeltnes, Heijboer, Stal, & Birkeland, 2003). Therefore, this stationary exercise could be a good way to start handcycling activities, allowing individuals to test and improve their ACE ability and endurance capacity before going out onto the road with a more difficult environment for handcycling. Indeed, the purpose of this study was to determine the effect of a stationary ACE training programme on level of autonomy, exercise performance, pulmonary functional parameters and HRV in individuals with post-traumatic CSCI.

2. Material and methods

2.1. Participants

The study included 11 participants (see Table I) with traumatic tetraplegia caused by a SCI at level between C4 and C7 (ASIA A or B), divided in two groups (higher or lower CSCI). ASIA A is defined as a person with no motor or sensory function preserved in the sacral segments S4-S5. ASIA B is defined as a person with sensory but not motor function preserved below the neurological level and includes the sacral segments S4-S5 (El Masry, Tsubo, Katoh, El Miligui, & Khan, 1996). The participants had no previous training experience after the SCI.

Table I. Main characteristics of the participants (mean ± SD).

Participant (number)	Group	Gender	SCI level (vertebra)	ASIA (score)	Age (years)	Time post SCI (years)	Body mass (Kg)
1	Higher cervical SCI	M	C4	A	24	5	62.1
2		M	C5	A	31	4	55.1
3		M	C5	A	46	24	71.9
4		M	C5	A	21	1	68.6
5		M	C5	A	49	29	85.7
6		F	C5	A	27	9	70.2
7	Lower cervical SCI	F	C6	A	39	12	67.4
8		M	C6	B	36	14	79.4
9		M	C7	A	46	25	67.9
10		M	C7	B	48	2	104.2
11		F	C7	B	34	19	62.5
					36.5 ± 10.0	13.1 ± 9.9	72.3 5 ± 13.4

In order to have a homogeneous group with similar abilities and physical activity levels, participants were selected from a larger group, excluding persons who practiced sports or exercised at least once a week. All 11 participants had functional biceps and deltoid muscles, but with different levels of motor ability. They were able to voluntarily bend their elbows, but only participants with C6-C7 CSCI could extend their elbows against gravity or opposition. None of them had grip ability.

Participants were informed of the possible beneficial effects and risks of their participation in the study, and gave their written consent to take part in the research project and for results and conclusions to be published. The study was approved by the University Ethics Committee and conformed to the principles outlined in the Declaration of Helsinki.

2.2. *Procedures*

The first series of measurements for all participants took place 1 week before the study (Week 0). Two sessions were conducted during the same week but not on the same day, in which the QIF questionnaire, resting HR recording, spirometric variables and maximum arm-crank power output (Ppeak) were measured. This complete series of measurements was repeated upon completion of the exercise programme (Week 9), split over 2 days and following the same order and schedule (in particular, the time of the HR measurement).

2.2.1. Quadriplegia index of function questionnaire. The QIF is a 37-item ordinal scale (range 0–100%) that measures human performance in terms of the ability to carry out activities of daily living (ADL), and awards each activity a score from 0 (completely assisted) to 4 (completely independent). The scale was specifically developed for persons with tetraplegia, and is sensitive to the effects of rehabilitation and physical training (Anderson et al., 2008; Gresham et al., 1986). The scale assesses feeding, bed activities, grooming, bathing, transfers, dressing, wheelchair mobility, bladder and bowel management, and understanding of personal care. A Spanish translation by the authors of the original QIF scale was used (Gresham et al., 1986; Marino et al., 1993). The same researcher carefully explained each item on the scale to the participants, and scored the corresponding item.

2.2.2. Arm-crank peak power output. Ppeak represents the peak mechanical power that participants are able to produce while arm-cranking (relative to body mass). It was measured using a SCIFIT PRO1 (SCIFIT Systems Inc, Tulsa, OK, USA) arm ergometer, adapted with a pair of grips specifically designed for persons with tetraplegia, the same ones that were used for the training sessions. This ergometer provides a wide range of adjustable crank heights and lengths to allow arm-cranking as in the training sessions. Participants were tested in their wheelchairs, with their trunk strapped to the back of the wheelchair and the wheelchair itself firmly strapped to the base of the ergometer. The cranking axis was set at the participant's chest level, always lower than shoulder height. Ergometer data was logged on a computer via an RS232 connection at a 1 Hz sample generated by the ergometer. The test consisted of five 10-second attempts to apply their maximum arm-crank power output, trying to increase their cadence against the resistance applied by the ergometer, with 3–5 min rest periods between attempts to avoid fatigue.

2.2.3. Heart rate variability. Resting HR was continuously recorded for 10 min as a first test for each measurement session, with the participant seated in their own wheelchair, under very quiet and dimly lit conditions and with an ambient temperature set at 22°C. As recommended, measurements for all participants were taken with their bladder almost empty (Ditor, Kamath, et al., 2005). Signals were recorded with a Polar RS800 monitor (Polar Electro, Finland) in beat-to-beat (RR) mode. Records were logged onto the computer through an infrared interface (Polar IR), using the Polar Pro Trainer 5 software (Polar Electro, Finland). HRV parameters were then calculated with the Kubios HRV 2.0 software (The Biomedical Signal and Medical Imaging Analysis Group, University of Kuopio, Finland), analyzing only the last 5 min of the recording in order to ensure stability of HR data. After appropriate filtering, correction and detrending, as recommended by the manufacturer (Tarvainen, Ranta-Aho, & Karjalainen, 2002), data was subjected to fast Fourier transform (FFT) spectral analysis, taking the standard recommended frequency bands (Task Force, 1996). HRV was determined using the following variables: average heart rate (HR); standard deviation of HR values (STD HR); square root of the mean squared differences between successive RR intervals (RMSSD); absolute power in the low frequency band (0.04–0.15 Hz) (LF); absolute power in the high frequency band (0.15–0.4 Hz) (HF); total spectral power (HRVPOWER); ratio between LF and HF (LF/HF).

2.2.4. *Spirometric variables.*

Pulmonary function was assessed by spirometry, and all spirometric variables were measured using a Fukuda Sangyo ST-250 spirometer (Fukuda Sangyo Inc., Japan). The same technician calibrated the spirometer daily and tested all the participants from a seated position. Reproducibility standards were those established by Miller et al. (2005). The spirometric variables measured were: Vital capacity (VC); Forced vital capacity (FVC); Maximum voluntary ventilation (MVV).

For the VC, FVC, and MVV tests, maneuvers were explained and demonstrated to participants following the recommended procedures (Miller et al., 2005). Belts or pant waists were loosened, and nose clips were worn. For the VC measurements, participants were encouraged to inhale completely and exhale maximally, and to sustain the effort for at least 6 s or longer. For the FVC test, participants were instructed to inhale completely and then exhale maximally, and to sustain the effort for at least 6 s or longer. Both tests were repeated 3 times. For the MVV test, instructions were given to perform at least 3 resting tidal breaths followed by breathing as rapidly and deeply as possible for 12 s. This test was carried out only once.

2.3. *Intervention*

The experiment consisted of ACE training performed on a stationary and mechanically-braked pedalling

Figure 1. Adjustable-height armcrank training machine.

machine, modified and converted to an adapted arm-crank machine. It was equipped with a pair of grips specifically designed for persons without grip ability and adjustable to the size and characteristics of the participant's hands and wrists (see Figure 1).

Participants trained for 8 weeks, twice a week, but never on consecutive days. Exercise duration in each session was from 15 to 20 min in the first 2 weeks, from 20 to 30 min in the third and fourth weeks, and from 30 to 40 min from the fifth week to the end of the training programme. Participants were instructed to keep a constant cadence throughout the training session and each participant was asked to choose a resistance he or she would be able to maintain during the proposed duration, with a rating of perceived exertion (Borg CR10 scale) between 2 and 3 (light to moderate).

2.4. *Statistical analysis*

All variables were checked for normality using the Kolmogorov-Smirnov test. In cases where distributions were skewed or heteroskedastic (LF, HF, and HRVPOWER), they were log-transformed, yielding transformed data with normal distribution (La Fountaine, Wecht, Spungen, & Bauman, 2010), thus allowing parametric statistics to be applied for comparisons. Nonetheless, for greater clarity and to facilitate comparison with other studies, the results for these variables are expressed as raw data.

A two-way ANOVA was implemented to all dependent variables (autonomy level and mechanical peak power output, pulmonary function and HRV parameters) including TIME (pre-training vs post-training) and INJLEVEL (higher vs lower CSCI) as factors. Whenever a significant main effect or interaction was identified, a least significant difference multiple range test (LSD-MRT) was used to confirm significant differences between the levels of the factors. A linear regression analysis was also performed between QIF and Ppeak. All statistical analyses were performed using the Statgraphics (v. 16.1.17), with an Alpha level set at 0.05. The meaningfulness of the outcomes was estimated through the effect size (ES, means divided by the standard deviation): an ES < 0.5 was considered small; between 0.5–0.8, moderate; and greater than 0.8, large (Cohen, 1988).

3. Results

3.1. *Functional and pulmonary variables*

Ppeak (W • kg^{-1}) significantly improved from pre to post-training in both higher and lower CSCI (Higher CSCI: 0.29 ± 0.23 vs 0.44 ± 0.26, $p < 0.01$, ES = 0.67; Lower CSCI: 1.03 ± 0.37 vs 1.35 ± 0.48, $p < 0.01$, ES = 0.83), whereas MVV (L/min) only improved in lower CSCI group (81.39 ± 34.18 vs 97.45 ± 28.11, $p = 0.03$, ES = 0.57). VC (L) and FCV (L) showed a slight but non-significant tendency ($p = 0.14$ and $p = 0.17$, respectively) to increase after the ACE programme. On the contrary, training programme did not significantly change QIF from pre to post-training ($p = 0.55$).

On the other hand, all functional and pulmonary variables showed significant differences between levels of injury, with higher values for participants with lower-level CSCI. This subset of results is depicted in Table II. Moreover, a significant 'Time x Injlevel' interaction was found for Ppeak and MVV, which explains the greater magnitude increase in both variables among lower CSCI (ES = 0.83 and 0.57 for Ppeak and MVV respectively) compared to higher CSCI (ES = 0.67 and 0.02 for Ppeak and MVV respectively).

3.2. *HRV variables*

HRVPOWER (ms^2) and LF (ms^2) showed a significant and large increase following the ACE programme in lower CSCI group (HRVPOWER: 351.98 ± 239.17 vs 627.58 ± 335.17, $p = 0.04$, ES = 1.06; LF: 169.37 ± 89.57 vs 379.3 ± 297.08, $p = 0.03$, ES = 1.07) (see Figure 2). STDHR (beats • min^{-1}) showed a strong but non-significant tendency ($p = 0.07$) to change from pre to post-training. No other significant changes were found after the ACE programme among HRV variables (see Table II). Unlike functional and pulmonary variables, none of the HRV variables showed differences between higher or lower CSCI levels and no 'Time x Injlevel' interactions were identified.

3.3. *QIF- Ppeak relationship*

QIF (%) and Ppeak (W • kg^{-1}) were significantly correlated before ($r = 0.88$; $p < 0.01$) and after ($r = 0.86$; $p < 0.01$) the training period. The simple linear regression model showed that Ppeak explained 74.42% of the variance of QIF.

4. Discussion

4.1. *Effect of exercise on functionality*

Our study demonstrates that an 8-week ACE training programme is able to increase exercise capacity in persons with both higher and lower CSCI, thus reinforcing previous studies in the field (McLean &

Table II. Functional, pulmonary and HRV variables (mean ± SD).

	PRE		POST		TIME factor	INJLEVEL factor	TIME x INJLEVEL interaction
	Higher (C4-C5)	Lower (C6-C7)	Higher (C4-C5)	Lower (C6-C7)			
QIF (%)	19.67 ± 20.02	59.4 ± 22.17	21.5 ± 19.6	64.4 ± 17.64	$p = 0.55$	$p < 0.01$ (LO > HI)	$p = 0.78$
Ppeak (W • kg^{-1})	0.29 ± 0.23	1.03 ± 0.37	0.44 ± 0.26	1.35 ± 0.48	$p < 0.01$ (POST > PRE)	$p < 0.01$ (LO > HI)	$p = 0.03$
VC (l)	2.42 ± 0.6	2.92 ± 1.06	2.46 ± 0.66	3.23 ± 0.96	$p = 0.14$	$p < 0.01$ (LO > HI)	$p = 0.24$
FVC (l)	2.27 ± 0.52	3.01 ± 0.87	2.38 ± 0.63	3.18 ± 0.81	$p = 0.17$	$p < 0.01$ (LO > HI)	$p = 0.66$
MVV (l/min)	74.44 ± 24.83	81.39 ± 34.18	74.83 ± 20.39	97.45 ± 28.11	$p = 0.03$ (POST > PRE)	$p < 0.01$ (LO > HI)	$p = 0.03$
HR (min^{-1})	74.5 ± 9.4	71.69 ± 7.95	71.74 ± 14.64	68.78 ± 6.05	$p = 0.34$	$P = 0.34$	$p = 0.97$
STDHR (min^{-1})	2.07 ± 0.64	2.02 ± 0.63	2.54 ± 0.86	2.29 ± 0.56	$p = 0.07$	$p = 0.44$	$p = 0.61$
RMSSD (ms)	17.45 ± 12.18	17.74 ± 10.63	31.11 ± 36.44	18.6 ± 7.56	$p = 0.24$	$p = 0.32$	$p = 0.30$
LF (ms^2)	204.54 ± 222.14	169.37 ± 89.57	370.24 ± 384.31	379.3 ± 297.08	$p = 0.02$ (POST > PRE)	$p = 0.40$	$p = 0.87$
HF (ms^2)	181.48 ± 310.91	128.27 ± 145.53	641.99 ± 1353.14	158.85 ± 148.79	$p = 0.24$	$p = 0.98$	$p = 0.89$
HRVPOWER (ms^2)	422.15 ± 482.42	351.98 ± 239.17	1082.73 ± 1556.15	627.58 ± 335.17	$p = 0.03$ (POST > PRE)	$p = 0.59$	$p = 0.90$
LF/HF	2.21 ± 1.75	2.78 ± 2.07	2.89 ± 1.76	3.63 ± 2.6	$p = 0.20$	$p = 0.27$	$p = 0.88$

Abbreviations: QIF. Quadriplegia Index of Function; Ppeak. arm-crank power output; VC. vital capacity; FVC. forced vital capacity; MVV. maximum voluntary ventilation; HR. average heart rate; STDHR. standard deviation of HR values; RMSSD. square root of the mean squared differences between successive RR intervals; LF. absolute power in the low frequency band (0.04–0.15 Hz); HF. absolute power in the high frequency band (0.15–0.4 Hz); HRVPOWER. total spectral power; LF/HF. ratio between LF and HF (LF/HF); LO. Lower-level cervical spinal cord injury; HI. Higher-level cervical spinal cord injury.

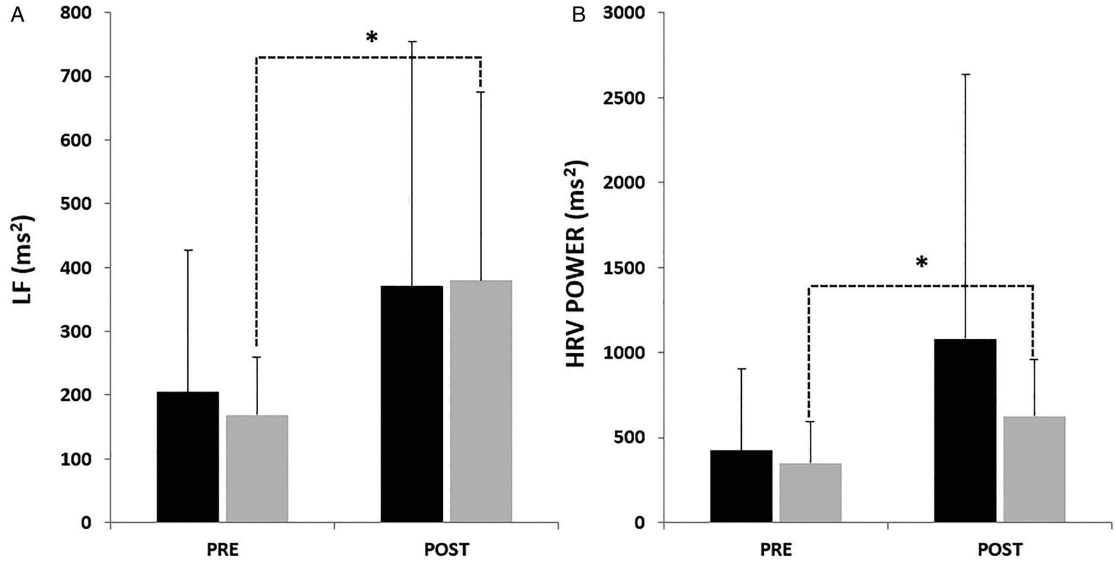

Figure 2. LF (panel A) and HRVPOWER (panel B) before and after the ACE training. Higher CSCI group is depicted in black bars and Lower CSCI group is depicted in grey bars. *Significantly different from pretraining ($p < 0.05$).

Skinner, 1995; Valent et al., 2009). On the other hand, as expected, persons with lower-level CSCI (C6-C7) presented higher pre-training Ppeak and QIF scores compared to those with higher-level CSCI (C4-C5), as previously reported (Anderson et al., 2008; Morgulec, Kosmol, Vanlandewijck, &

Hubner-Wozniak, 2005). The improvement in power output could be the result of improved gross mechanical efficiency due to better arm and shoulder coordination rather than a gain in muscle strength during ACE (de Groot et al., 2003; Valent et al., 2009).

However, although all participants increased their power output, QIF score results did not show a statistically significant increase in the ability to perform ADL, which initially appears contrary to the conclusions of authors such as Gresham et al. (1986) and Anderson et al. (2008), who refer to the QIF scale as 'sensitive to the effects of rehabilitation and physical training' and also contrary to others authors (Dallmeijer et al., 2004; Dallmeijer & van der Woude, 2001) who suggest that increasing the arm-crank power output of persons with tetraplegia could be related to an improvement in their functional abilities and individual autonomy. In fact, our results showed that Ppeak explained a large percentage of the variance of QIF. Nevertheless, we think that time could be essential in this process for the individual to apply such strength gains to ADL and try out new activities such as transfers, dressing, wheelchair mobility or personal care, and eventually attain a higher level of individual autonomy and functionality as measured by the QIF score. Therefore, either a longer intervention or a delayed post-training measurement would be required to observe an improvement in this variable.

4.2. *Effect of exercise on respiratory system*

The fact that the lower-level CSCI group had higher measured values of VC, FVC and MVV than the higher-level CSCI group in the pre-training situation may account for the different functional levels of respiratory muscles. Spirometric results also showed that, after ACE training, there was a significant increase in MVV in the lower CSCI group, a variable that has been shown to be affected in neuromuscular disorders (Rochester & Esau, 1994; Tow et al., 2001). This is probably due to the general increase in function of some skeletal muscles involved in respiration. Regarding the absence of changes in FVC following the intervention, our results are in line with those of Valent et al. (2009), but contrary to those of Crane et al. (1994), who found an improvement in that variable. This discrepancy could be due to the fact that in the study by Crane et al. (1994) the participants were already trained persons. Nevertheless, more insight into the function of respiratory muscles might be gained by measuring inspiratory and expiratory pressures, since these are strongly affected in CSCI (Bodin et al., 2003; Rochester & Esau, 1994) and are therefore likely to show greater improvement than volumes after a period of training.

Based on our findings in a small group of novice exercisers where the lower-level CSCI group significantly improved MVV and the higher-level CSCI group did not, persons with lower-level CSCI appear to have greater pulmonary adaptations to ACE training than persons with higher-level CSCI. It could be argued that a greater pulmonary capacity in persons with a highly decreased exercise capacity, as it is the case for persons with CSCI, enables greater intensity in the training programme and eases the achievement of larger improvements, as observed in our study for lower CSCI. This difference should be taken into account when programming exercise training and evaluating performance, and also when studying epidemiology or respiratory processes in CSCI.

4.3. *Effect of exercise on HRV*

Baseline HRV values obtained in this study are similar to other data published for persons with CSCI (La Fountaine et al., 2010; Millar et al., 2009; Takahashi et al., 2007; Wecht et al., 2006). HRV has been previously used to measure the level at which persons with SCI are affected by the loss of autonomic balance. Indeed, some authors found differences in both LF and HF components when comparing persons with tetraplegia and paraplegia to individuals without SCI (de Carvalho Abreu, Dias, Lima, de Paula Junior, & Lima, 2016); some authors found differences only in LF component (Bunten et al., 1998), while others failed to find differences in either LF or HF component (Takahashi et al., 2007). The absence of differences in our study when comparing HRV between higher- and lower-level CSCI may support the hypothesis that both groups have the same degree of injury to the descending sympathoadrenal pathway jointly with intact vagal afferent and efferent pathways (Takahashi et al., 2004).

The main finding of the present study is that 8 weeks of ACE training for individuals with SCI are sufficient to significantly improve overall HRV, measured in the frequency domain (HRVPOWER and LF). Our findings partially differ from those previously reported by other authors. Disagreement with the Millar et al. (2009) study could be due to the fact that all our participants had a CSCI between C4 and C7, whereas their sample was fairly heterogeneous (SCI between C5 and T10). Besides, their different mode of exercise, together with a shorter treatment (12 vs. 16 training sessions, 4 vs. 8 weeks), may explain why they failed to find significant differences in linear and frequency domain HRV indices. On the other hand, the study by Ditor Macdonald et al. (2005) included a small and heterogeneous sample (6 subjects, C4-T12), which might have precluded the authors from finding statistically significant changes in their HRV measurements.

Interestingly, our results showed an increase in LF, whereas previous studies have been unanimous in reporting no changes or a reduction in LF power after training (Ditor, Kamath, et al., 2005; Ditor, Macdonald, et al., 2005; Millar et al., 2009). Although such an increase in LF power could be attributable to an enhancement of sympathetic activity in non-SCI persons (Task Force, 1996), taking into account that sympathetic branch of ANS is impaired in our population (Bunten et al., 1998), we propose that the rise in the LF component of HRV might be caused at a high degree by parasympathetic outflow, as previously suggested (Takahashi et al., 2007). Therefore, LF increase following the ACE intervention would represent an enhanced vagal modulation of HR dynamics. Moreover, if we bear in mind that persons with SCI have autonomic dysfunction and increased risk of CV disease (Claydon & Krassioukov, 2008; Myers et al., 2007), our results could be especially relevant in preserving CV function in people with SCI and irrespectively of an improvement in daily life functioning.

5. Conclusions

Two main outcomes are reflected by our findings: (a) with respect to exercise trainability in persons with CSCI, even individuals with higher CSCI (C4-C5) are able to perform a regular ACE training programme that improves their power output; (b) with regards the adaptations that ACE training induces in such a population, we have demonstrated that persons with lower-level CSCI retain their ability to increase resting HRV and improve respiratory function in response to a period of ACE training, despite no immediate improvement in their ability to perform ADL.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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