Chapter 6

AEROBIC EXERCISE TRAINING IN POST-POLIO SYNDROME: PROCESS EVALUATION OF THE FACTS-2-PPS TRIAL

To be submitted

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ABSTRACT

Objective: A recent study failed to show improvements in cardiorespiratory fitness through a home-based high intensity aerobic exercise program in post-polio syndrome (PPS). We performed a process evaluation to explore reasons for the lack of efficacy by quantifying actual training dose and evaluating the effect of the program on muscle function.

Methods: Forty-four individuals with PPS were randomized to exercise therapy (n=22) or usual care (n=22). Participants exercised 3 times weekly for 4 months on a bicycle ergometer (>60% heart rate reserve). We determined the training time spent within the designated target heart rate range, as well as the time at or above the anaerobic threshold (AT). For muscle function, we measured muscle endurance.

Results: The attendance rate was high (median 89%), but nobody trained within the target heart rate range >75% of the designated time. Instead, participants exercised at lower intensities; around the AT most of the time. We found no improvement in aerobic capacity: muscle endurance (1.6%, 95%CI -10.6 to 13.7) nor cardiorespiratory fitness (submaximal heart rate, -0.3 beats per minute, -7.8 to 7.2) increased in the exercise group, compared to usual care.

Conclusions: Individuals with PPS were unable to adhere to a high intensity aerobic training program on a bicycle ergometer. Despite exercise intensities around the AT most of the training period, aerobic capacity did not improve. The lack of efficacy on muscle function does not support the assumption of deconditioning of muscles of the lower extremities in PPS.
INTRODUCTION

Individuals with post-polio syndrome (PPS) generally report fatigue as their main problem.\(^1,2\) This fatigue is known to be multidimensional and consists, besides cognitive and psychological components also of physical aspects.\(^3\) One of the factors responsible for physical fatigue may be a reduced aerobic capacity resulting from a lower physical activity level.\(^4,5\) Recently, we reported the results of a randomized controlled trial on the efficacy of exercise training (FACTS-2-PPS trial) that failed to show improvements in fatigue through a 4-month exercise therapy intervention with a home-based high intensity aerobic exercise program.\(^6\)

In the FACTS-2-PPS trial we also observed no change in cardiorespiratory fitness, assessed from heart rate response, following the 4-month exercise program.\(^6\) This contradicts findings of several previous studies, showing the potential of aerobic training in PPS.\(^7,8\) Clarifying the reasons for the lack of efficacy of the FACTS-2-PPS exercise program may provide insight in the potential role of aerobic training and optimal training methods for alleviating fatigue symptoms in PPS.

One possible explanation for the lack of efficacy is that individuals could not adhere to the program. During the 4-month program, designated training intensity was gradually increased from 60% heart rate reserve (HRR) to 70% HRR, in accordance with the American College of Sports Medicine (ACSM) guidelines for aerobic training in healthy subjects and persons with chronic diseases.\(^9\) In addition, training duration was increased from 28 to 38 minutes. Although it has been reported that individuals with PPS tolerate such high intensity programs,\(^7,8,10-13\) most of these studies provided incomplete or no insight in the training intensity and duration actually achieved. It is therefore currently still uncertain whether individuals with PPS can adhere to an aerobic training program based on these guidelines.

Also, the optimal training dose (in terms of intensity and duration), its relationship with the subsequent training response and the mechanisms of improvement are currently still unknown in PPS. It is well known that regular aerobic training induces both central (i.e. cardiorespiratory) and peripheral (i.e. muscular) adaptations.\(^14\) Furthermore, it is known that improvement of cardiorespiratory fitness requires involvement of large muscle groups to impose an adequate stimulus for adaptations.\(^15\) Possibly, the FACTS-2-PPS exercise program did result in muscular adaptations, which, due to the reduced muscle mass of the lower extremities, did not lead to an increased cardiorespiratory fitness. On the other hand, if no muscular adaptations occurred following the exercise program, this indicates that training dose was apparently insufficient to induce a positive training response.

In the current study we present the results of a process evaluation of the exercise intervention of the FACTS-2-PPS trial. We investigated the following research questions: (1) Are individuals with PPS able to adhere to a 4-month high intensity home-based aerobic training? (2) Does a high intensity home-based aerobic training result in improved muscular function? (3) To what extent does actual training dose explain the variance in training response?
Chapter 6

METHODS

The data used in the present study comes from the multicenter FACTS-2-PPS trial on the efficacy of exercise therapy (ET) and cognitive behavioral therapy (CBT) on reducing fatigue, and improving activities and quality of life in PPS. Two previous publications describe the study design\(^\text{16}\) and the main results\(^\text{6}\) of the trial. In the present study we compared the group allocated to ET to the usual care (UC) group. Outcomes in both groups were assessed at baseline (pre-treatment) and after 4 months (post-treatment). Two assessors, who were blinded for treatment allocation, tested participants at each occasion.

Participants

Participants were recruited from 7 hospitals and rehabilitation centers throughout the Netherlands. Participants were initially screened by a physician to check the in- and exclusion criteria. Inclusion criteria were: diagnosis of PPS according to the criteria as published by the March of Dimes\(^\text{1}\); severe perceived fatigue (subscale fatigue severity of the Checklist Individual Strength (CIS20-F) ≥35);\(^\text{17}\) age between 18 and 75 years; life-expectancy longer than 1 year; walking-ability at least indoors with or without walking aid; and ability to cycle on a cycle ergometer against a load of at least 25 Watts. Exclusion criteria are described elsewhere.\(^\text{16}\) The medical ethics committees of the hospitals and rehabilitation centers involved approved the study protocol, and written informed consent was obtained from all participants.

Interventions

UC: The participants in the UC and ET group all received usual care. Usual care for PPS could include the use of assistive devices and/or orthoses, physical therapy, and medication use. Participants were not restricted in their activities.

ET: Exercise therapy lasted 4 months and consisted of (1) a home-based aerobic training program on a bicycle ergometer 3 times weekly and a (2) supervised group training containing muscle strengthening and functional exercises once a week.

(1) Participants were supplied with a bicycle ergometer (Kettler X7, Germany) and a logbook containing the training scheme. In the logbook, participants documented the number and duration of treatment sessions, their perceived exertion of the training on the Borg Scale (range 6–20 )\(^\text{18}\) and possible complaints after the training session. Training intensity was gradually increased from 60% to 70% of the estimated HRR. The HRR was calculated as the difference between the predicted maximal heart rate (220 minus age)\(^\text{19}\) and the heart rate at rest. Participants were instructed to monitor the training intensity by checking their hear rate (HR), which was continuously measured by HR monitors (Polar RS400, Polar Electro Nederland, Almere, The Netherlands). Duration of the training sessions was gradually increased from 28 to 38 min per session (including 5 min warming-up and 5 min cooling-down) and sessions were divided into prescribed exercise bouts, which were interspersed with short rest periods of unloaded cycling. The duration of exercise bouts was increased from 2 min at the start of the program to 13 min at the end of the program. Feasibility of the training scheme was checked weekly by one of the therapists by reading the HR monitors and checking the logbooks.
(2) The supervised group training consisted of strengthening exercises and functional exercises in 1-hour group sessions. The therapist selected functionally relevant muscles for strengthening exercise before the start of the program. Functional exercise selection was based on the best expected effects on physical functioning.

**Outcomes**

**Adherence:** The attendance rate of ET was assessed by recording the fraction of home-based training sessions as recorded in the participants’ logbooks. To determine whether participants adhered to the designated training program, we used the data from the HR monitors to establish the total time that participants trained in their prescribed target HR range (60% to 70%HRR). Individuals were considered adherent if they exercised >75% of the possible time in their prescribed target HR range.

In addition, we established the total time that participants trained at or above the HR corresponding to their anaerobic threshold (AT). This is of interest because the AT is often used to target training intensity, in healthy subjects and individuals with chronic disease. We recently demonstrated that the recommended training intensity based on current guidelines is above the AT in many individuals with PPS, especially when target intensity is set at 60%HRR or higher. Besides evaluating whether individuals with PPS can adhere to a high intensity program, we therefore also established whether they are capable of exercising at or above their AT. We considered this to be the case if individuals trained >75% of the possible time at or above their AT. The AT was determined by 2 independent experienced researchers, through visual inspection of the gas exchange plots from the pre-treatment submaximal incremental exercise test using the V-slope method.

**Muscle function:** For muscle function, we assessed both muscle endurance and strength. As a measure of muscle endurance we determined the fatigue resistance of the knee extensor muscles (at 60° knee flexion) by a series of intermittent electrically evoked isometric contractions (150 contractions of 1 s duration and 1 s of rest in between) with the use of a fixed dynamometer. Fatigue resistance was defined as the percentage torque remaining during the last minute of the protocol. Measurements were performed on the weakest leg, unless during manual muscle testing grading of knee extension strength was <3, according to the Medical Research Council Scale (MRC). An extensive description of the protocol can be found elsewhere.

For muscle strength we measured the maximal voluntary torque (MVT) of the knee extensor muscles isokinetically between 90° and 30° knee flexion at a velocity of 60°/s using a fixed dynamometer (Biodex System 3, New York, USA). The MVT of each leg was measured separately and we included the best of 3 maximal efforts in the analysis. If the MRC-score was <3, strength measurements were not performed. Data for isokinetic strength measurements are presented both for the strongest leg and the weakest leg.

**Cardiorespiratory fitness:** The previously reported results, indicating no change in the cardiorespiratory fitness following training, solely considered the submaximal HR response as prespecified outcome measure. However, other indices of HR and gas exchange outcomes, as well as values of perceived exertion could reveal possible cardiorespiratory adaptions.
From the submaximal incremental cycle ergometry tests, we assessed changes in resting heart rate, oxygen consumption at the AT, submaximal oxygen consumption (\(\text{Vo}_{2\text{submax}}\)), submaximal respiratory exchange ratio (\(\text{RER}_{\text{submax}}\)), and submaximal ratings of perceived exertion (\(\text{RPE}_{\text{submax}}\)). \(\text{Vo}_{2\text{submax}}, \text{RER}_{\text{submax}}\) and \(\text{RPE}_{\text{submax}}\) were assessed at the highest similar submaximal workload that was achieved both during the pre- and post-treatment assessment (i.e. the workload differed between participants but within participants the same standardized workload was used for comparison).

**Adverse effects**

All adverse events (such as severe muscle fatigue, joint pain, or other events considered to be related to ET) reported spontaneously by the participants or observed by the therapist were recorded and followed until they abated or until a stable situation had been reached.

To evaluate whether the training program resulted in muscular overload, blood samples were taken to determine serum creatine kinase (CK) activity as an index of muscle damage. CK activity levels were determined pre-treatment, 5 and 10 weeks after the start of the intervention and post-treatment.

**Statistical analysis**

Descriptive statistics were used to characterize the sample. For normally distributed data, we used the paired-samples \(t\) test to test differences within the groups and the Student \(t\) test to test differences between groups; in case of non-normally distributed data, the Wilcoxon signed-rank test and Mann-Whitney \(U\) test were used. To study the course of CK activity levels during the intervention period in the ET group, we used the Friedman test.

Using a linear regression model, we determined the extent to which the actually achieved training dose explained the variance in submaximal HR change (\(\Delta\text{HR}_{\text{submax}}\)). Session training doses (calculated as the duration of the session multiplied by the mean %HRR for that session) were added up for each participant to obtain the total actual training dose. We visualized the relationship in a plot. Statistical analyses were performed with the SPSS statistical software package (version 20.0.0.1). An alpha level of 0.05 was used for all tests of significance.

**RESULTS**

In total 44 participants were included in the analyses (22 in UC and 22 in ET). The flow of participants through the study is reported elsewhere. Table 1 shows the characteristics of participants in the UC and ET group.

Figure 1 shows that the attendance rate for the aerobic exercise sessions at home was high (median 89%). Eight participants (36%) attended <75% of the possible sessions. The 3 most frequently reported reasons for missing a training session were fatigue, illness and muscle pain.

Three participants used beta blockers. In addition, due to technical problems, HR data was incomplete in 5 other participants. HR data in the remaining participants (n=14) showed
that nobody trained within their designated target HR range >75% of the possible time (Fig. 2). Group mean values for the mean duration achieved during the sessions for each week of the program are presented in Figure 3A, illustrating that training duration increased in accordance with the protocol. Figure 3B shows the group mean values for the mean HRR achieved during the exercise bouts for each training week. There was a pattern of increasing intensity throughout the entire training program, but, in all except 2 participants, it remained below designated intensities.

We identified the AT in 18 participants (82%) of whom 14 had complete training HR data. Most of these participants (71%) trained >75% of the possible time at or above the HR corresponding to their AT (Fig. 4). Participants who attended >75% of possible sessions, all trained >75% of the possible time at or above their AT.

Ratings of perceived exertion during the training sessions were incomplete (data in <80% of the sessions) in 9 participants. In the remaining participants (n=14), the perceived exertion showed an increasing pattern throughout the entire training period (Fig. 5). The percentage of participants who rated at least half of the weekly training sessions as 12 or higher on the Borg Scale increased from 71%, to 91%, to 100% in the 1st, 8th and 16th week of the program, respectively.

Table 1. Participant characteristics.

<table>
<thead>
<tr>
<th>ET (n=22)</th>
<th>UC (n=22)</th>
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<tbody>
<tr>
<td>Demographic data</td>
<td></td>
</tr>
<tr>
<td>Mean age (y)</td>
<td>60.1±7.4</td>
</tr>
<tr>
<td>Female (%)</td>
<td>11 (50%)</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>26.5±3.4</td>
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</table>

<table>
<thead>
<tr>
<th>Polio characteristics</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Age at acute polio (y)</td>
<td>3 (1–40)</td>
<td>2 (0–16)</td>
</tr>
<tr>
<td>Time since new symptoms (y)</td>
<td>13.2±7.7</td>
<td>14.6±9.5</td>
</tr>
<tr>
<td>Present walking distance, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Around the house</td>
<td>9 (41%)</td>
<td>6 (27%)</td>
</tr>
<tr>
<td>Seldom further than 1km</td>
<td>8 (36%)</td>
<td>11 (50%)</td>
</tr>
<tr>
<td>Regularly further than 1km</td>
<td>5 (23%)</td>
<td>5 (23%)</td>
</tr>
<tr>
<td>MMT testing sum score legs</td>
<td>67.8 (41.8–80.0)</td>
<td>69.6 (43.0–80.0)</td>
</tr>
<tr>
<td>MMT testing sum score arms</td>
<td>50.0 (32.0–50.0)</td>
<td>50.0 (16.8–50.0)</td>
</tr>
</tbody>
</table>

Data are mean ± SD, number (%), or median (range).
Abbreviations: ET, exercise therapy; UC, usual care; BMI, body mass index; MMT, manual muscle testing.
*Walking distance was defined as the daily distance walked and was classified in 4 categories: 1 (indoors only), 2 (around the house), 3 (seldom >1km), and 4 (regularly >1km).
*Sum score for muscle strength of the legs was calculated by adding 16 muscle groups. Each muscle group had a score between 0 and 5, sum score ranged from 0 to 80.27
*Sum score for muscle strength of the arms was calculated by adding 10 muscle groups. Each muscle group had a score between 0 and 5, sum score ranged from 0 to 50.27
Chapter 6

**Figure 1.** Individual attendance rates in the exercise therapy group.

**Figure 2.** Total time within the target heart rate range for participants in the exercise therapy group.

**Figure 3A.** Group mean values (± SD) for training duration achieved during the training sessions for each week of the program. Grey bars indicate designated duration; black bars indicate the actually achieved duration.
Figure 3B. Group mean values (±SD) for intensity sustained during the exercise bouts for each week of the program. Grey bars indicate designated intensity; black bars indicate the actually achieved intensity.

Figure 4. Total time at or above the heart rate corresponding to the anaerobic threshold for participants in the exercise therapy group.

Figure 5. Group mean values (±SD) for the perceived exertion of training sessions for each week of the training program.
<table>
<thead>
<tr>
<th></th>
<th>ET</th>
<th>UC</th>
<th>ET vs UC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Pre-treatment</td>
<td>Post-treatment</td>
</tr>
<tr>
<td>Muscle endurance and strength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue resistance (% remaining torque)</td>
<td>3</td>
<td>46.3±2.5</td>
<td>53.7±6.5</td>
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<tr>
<td>MVT strongest leg (Nm)</td>
<td>16</td>
<td>100.3±41.6</td>
<td>105.1±39.1</td>
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<tr>
<td>MVT weakest leg (Nm)</td>
<td>11</td>
<td>76.3±40.7</td>
<td>79.3±45.0</td>
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<tr>
<td>Cardiorespiratory fitness</td>
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<td></td>
<td></td>
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<tr>
<td>Submaximal HR (bpm)</td>
<td>18</td>
<td>121.0±14.1</td>
<td>119.0±12.0</td>
</tr>
<tr>
<td>Resting HR (bpm)</td>
<td>18</td>
<td>74.2±8.0</td>
<td>77.1±13.2</td>
</tr>
<tr>
<td>AT (mL/min/kg)</td>
<td>13</td>
<td>15.5±4.4</td>
<td>16.3±4.3</td>
</tr>
<tr>
<td>Submaximal VO₂ (mL/min/kg)</td>
<td>19</td>
<td>17.1±4.6</td>
<td>17.0±4.7</td>
</tr>
<tr>
<td>Submaximal RER</td>
<td>19</td>
<td>0.94±0.09</td>
<td>0.94±0.06</td>
</tr>
<tr>
<td>Submaximal RPE</td>
<td>19</td>
<td>13.5±2.0</td>
<td>12.9±2.0</td>
</tr>
</tbody>
</table>

Abbreviations: ET, exercise therapy; UC, usual care; CI, confidence interval; MVT, maximal voluntary torque; HR, heart rate; VO₂, oxygen consumption; RER, respiratory exchange ratio; RPE, rating of perceived exertion.
Table 2 shows the outcomes pre- and post-treatment, together with the difference in change scores between ET and UC. We found no significant intervention effect of ET for muscle endurance (1.6%, 95%CI -10.6 to 13.7) and muscle strength (strongest leg 2.0Nm, 95%CI -10.2 to 14.2; weakest leg 0.7Nm, 95%CI -15.0 to 16.5) compared to UC. Also, we found no change in muscle function within both groups, and there were no significant differences within and between the groups for any of the cardiorespiratory fitness measures.

Figure 6 shows that training dose was not associated with the $\Delta HR_{submax}$ ($R^2=0.024, p=0.565$).

Three adverse events were reported in the ET group (joint pain of the knee and elbow, and trochanteric bursitis). In 1 patient this led to discontinuation of the intervention. All 3 adverse events were resolved. CK activity levels pre-treatment (median 105.5 U/L, inter-quartile range 71.3–266.3 U/L) were above reference values of healthy individuals in 9 of the 22 participants (41%). Values did not change significantly over time ($p=0.552$).

**DISCUSSION**

In the present study, the training dose, in terms of intensity and duration during a high intensity home-based aerobic training program was quantified in a group of individuals with PPS. Despite the high attendance rate, participants were not able to adhere to the high intensity training program. Nevertheless, participants instead exercised at or little above their AT most of the training period but this did not result in improved muscle function or cardiorespiratory fitness. Our results confirmed that the training program is safe, but not effective in increasing the aerobic capacity of individuals with PPS.

Even though participants attended most training sessions, our results clearly demonstrate that only few of them seem capable of exercising at high intensities (>60 %HRR) for prolonged periods of time. This is surprising, given earlier reports that high intensity training programs are well tolerated by individuals with PPS. From these reports, we found only 2 studies describing the mean duration and intensity actually achieved during training sessions. Participants in the 4-month aerobic exercise program of Jones and colleagues,
for example, were able to adhere to designated intensities of 70–75% HRR; the mean HR during the training period represented 69.2% HRR. The higher HRR achieved during their training program may result from the seemingly better exercise capacity pre-treatment and younger age of participants compared to our study group. Comparison is however hampered by the lack of information about demographics and polio characteristics. Furthermore, little information was provided about individual variation. Based on the marked individual variations in the actually achieved training dose found in the present study, it may well be that in the Jones study, not all participants could sustain high intensities. This is corroborated by the fact that, as mentioned by the authors, in some participants, duration and intensity had to be adjusted downward. Modifications in exercise intensity were also required in the study by Kriz and colleagues, who showed that the mean HR during their arm ergometry training program represented only 50% HRR, while target intensity was set at 70%–75% HRR, a pattern similar to our study. Based on these findings, it may therefore be concluded that, for most individuals with PPS, high exercise intensities seem too exhausting to sustain during training.

While high intensities were difficult to sustain, participants exercised at or above their AT during most of the training period. Participants rated most training sessions as 12 or higher on the Borg Scale, which is in line with findings from a recent study showing that in PPS, the HR attained at the AT corresponds well to a score of 12 on the Borg Scale. Nonetheless, against our expectations, we found no indications of increased cardiorespiratory fitness levels following the aerobic training program.

It may be that our training program resulted in positive muscular adaptations, which, due to the reduced muscle mass of the lower extremities, did not lead to an increased cardiorespiratory fitness. However, as for the cardiorespiratory fitness, we found no indications of an improved muscle function – i.e. neither muscle endurance nor muscle strength significantly improved in the ET group, compared to UC. It is important to realize though that findings regarding muscle function, especially those for endurance, should be interpreted with caution because they are based on a small number of observations. Possibly, the presence of muscular adaptations could not be detected due to the small sample size.

When assuming that muscle function was indeed not improved as a consequence of the training program, this indicates that, apparently, the training dose was not sufficient to induce positive training effects. The absence of muscular adaptations in our study is consistent with findings from Willén and colleagues who also found no changes in knee extensor muscle function following a 5-month dynamic water exercise program. Contrary, Ernstoff and colleagues found an increased muscle strength in some – mainly upper extremity – muscle groups, as well as an increased fatigue resistance of the weaker leg, though without any change in aerobic enzyme activity or cross-sectional areas of the muscle fibers. A possible explanation for the absence of muscular adaptations in our study is that the involved muscles were, apart from the reduced muscle mass, not deconditioned in most individuals. We recently found that fatigue resistance of the knee extensor muscles in PPS was not different from healthy subjects. Possibly, this muscle group, has already adapted considerably in response to the relative higher loading during daily life activities. This is supported by findings of extensive type I fiber predominance and fiber type hypertrophy. It may therefore be difficult to improve muscular function and cardiorespiratory fitness through
exercise that is primarily performed with lower extremities. The increased cardiorespiratory fitness found by Willén, Ernstoff, and colleagues could be explained by the fact that their training programs were aimed at whole body exercise, whereas our training program only included training of the lower extremities.

Furthermore, we found that training dose was not associated with the change in cardiorespiratory fitness. This contrasts findings in runners and young soccer players, where explained variance values ranging from 45% to 76% were reported. A possible explanation for this inconsistency relates to the different methods used for calculating the individual training dose. Had we used a more individualized approach, based on the individual physiological response, this may have resulted in a stronger association. On the other hand, in healthy persons, the large variability in the way individuals react to training is, besides training dose, also influenced by several other factors such as the subjects’ initial fitness level, psychological factors and genetics. It is therefore conceivable that in PPS, other, probably disease specific factors, play a major role as well. One factor that may be of major importance in PPS is the pretraining muscle function and, therewith the potential for trainability of muscles.

Strengths and limitations

A strength of the present study is that we carefully monitored HR of individuals during their home-based training program, enabling us to quantify the actual training dose. The finding that, contrary to earlier reports most individuals with PPS were unable to adhere to a high intensity program emphasizes the necessity to monitor the actually achieved training dose and to reconsider the application of such programs in clinical practice. The fact that we did not select participants based on the presence of deconditioning could be considered a limitation of the present study. Hypothetically, deconditioned participants have more potential to benefit from aerobic training. A more targeted selection, aimed at patients with deconditioned muscles, may have yielded better treatment effects.

Clinical implications

Increasing the aerobic capacity through exercise may be possible in PPS, provided that training programs are highly individualized with respect to the aerobic (muscle) capacity. In some individuals, the muscles that are required for activities in daily life have probably already been largely adapted as a consequence of extensive use, limiting the potential for muscle adaptations. Therefore, for those individuals, increasing the aerobic capacity may be possible by using exercise modes that require the use of other large muscle groups instead.

In other individuals, the muscles that are required for daily tasks may be deconditioned due to physical inactivity. In this case, exercise modes should be selected that require the use of those deconditioned muscle groups, in order to improve the aerobic (muscle) capacity. Therefore, when prescribing aerobic exercise, one should determine whether functionally important muscle groups are underloaded during daily life activities. If this is the case, those muscle groups should be involved in the training regime. If not, other exercise modes should be considered.
Even though it remains uncertain whether there exists a training intensity below which no improvement occurs with training, we now know that, for most individuals with PPS intensities of >60\%HRR are too exhausting to sustain during training. Instead training intensity prescription based on the AT or alternatively on RPE, rather than on a fixed percentage of the HRR for the entire study group, offers a more individualized target for aerobic training in PPS. Whether this can also be applied to other exercise modes such as arm ergometry or four limb ergometry is uncertain and requires further investigation.

Conclusion

Despite a high attendance rate, individuals with PPS seem unable to adhere to a high intensity home-based aerobic training program on a bicycle ergometer. Although participants, instead trained around their AT most of the training period, the program did not result in an increased aerobic capacity, as neither cardiorespiratory fitness nor muscle function improved. A possible next step is to study the efficacy of training programs based on exercise modes tailored to the individual’s aerobic (muscle) capacity. This information would facilitate the development of highly individualized training programs that may eventually alleviate fatigue in individuals with PPS.
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