

ORIGINAL ARTICLE

Determining the Anaerobic Threshold in Postpolio Syndrome: Comparison With Current Guidelines for Training Intensity Prescription



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Abstract

Objectives: To determine whether the anaerobic threshold (AT) can be identified in individuals with postpolio syndrome (PPS) using submaximal incremental exercise testing, and to compare current guidelines for intensity prescription in PPS with the AT.

Design: Cohort study.

Setting: Research laboratory.

Participants: Individuals with PPS (N=82).

Interventions: Not applicable.

Main Outcome Measures: Power output, gas exchange variables, heart rate, and rating of perceived exertion (RPE) were measured in an incremental submaximal cycle ergometry test. Two independent observers identified the AT. Comparison of current guidelines for training intensity prescription in PPS (40%–60% heart rate reserve [HRR] or RPE of 12) with the AT was based on correlations between recommended heart rate and the heart rate at the AT. In addition, we determined the proportion of individuals that would have been recommended to train at an intensity corresponding to their AT.

Results: The AT was identified in 63 (77%) of the participants. Pearson correlation coefficients between the recommended heart rate and the heart rate at the AT were lower in cases of 40% HRR ($r = .56$) and 60% HRR ($r = .50$) than in cases of prescription based on the RPE ($r = .86$). Based on the RPE, 55% of the individuals would have been recommended to train at an intensity corresponding to their AT. This proportion was higher compared with 40% HRR (41%) or 60% HRR (18%) as criterion.

Conclusions: The AT can be identified in most individuals with PPS offering an individualized target for aerobic training. If the AT cannot be identified (eg, because gas analysis equipment is not available), intensity prescription can best be based on the RPE.

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Physical therapy recommendations for individuals with neuromuscular diseases (NMDs) include aerobic exercise training to prevent or reverse deconditioning and preserve muscle endurance

for daily life activities.¹ Determining the desired training intensity is delicate in NMDs because exercise levels should be sufficiently intense to stimulate a training effect; however, they should avoid muscular overload.²

Most guidelines for aerobic training in healthy subjects recommend training intensities relative to the individual's maximal capacity in terms of maximum oxygen consumption or maximal heart rate.³ In NMDs, however, a true maximum oxygen consumption or maximal heart rate is often not reached because the leg muscles frequently fatigue before the cardiorespiratory system reaches its maximum. Therefore, in these patient groups, maximal heart rate is often estimated based on age. Another

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method to prescribe training intensity uses ratings of perceived exertion (RPEs), often used in individuals using beta-blocking agents.⁴ Our experience with training in individuals with post-polio syndrome (PPS), a slowly progressive NMD, is that when applying these guidelines physical therapists often have to adjust the intensity. This is probably because none of these guidelines make use of a direct indicator of aerobic capacity, resulting in an exercise prescription insufficiently tailored to the individual.

The anaerobic threshold (AT), a direct indicator of aerobic capacity,⁵ may be useful to overcome this problem. The AT is widely used for setting target intensity for aerobic training in healthy subjects⁶ and individuals with chronic disease (eg, multiple sclerosis,⁷ coronary heart disease,⁸ hypertension,⁹ obesity¹⁰). Usually, the AT is assessed through graded maximal exercise testing.¹¹ In PPS and other NMDs, maximal exercise testing is not feasible in all individuals because performance is often symptom limited.^{12,13} Furthermore, maximal exercise may provoke muscle complaints and excessive fatigue with a prolonged recovery and should, therefore, be avoided.⁴ Submaximal exercise testing could provide an alternative with reduced physiological stress in at least some individuals; however, the risk lies in insufficient stressing of the cardiorespiratory system to identify the AT.

Our aim was to determine whether the AT in individuals with PPS can be identified through submaximal exercise testing. In addition, we compared commonly used markers for training intensity based on the estimated heart rate reserve (HRR) and RPEs according to current guidelines with the AT. In this process we realized that expensive gas analysis equipment is often not available in physical therapy practices.

Methods

Participants

Eighty-two individuals with PPS were recruited. Sixty-six participants performed the test as part of an ongoing clinical trial of the efficacy of exercise therapy and cognitive behavioral therapy to improve fatigue, daily activity performance, and quality of life in PPS.¹⁴ The remaining 16 participants performed the test as part of a cross-sectional study investigating the aerobic exercise capacity in individuals with PPS. Participants were recruited from Dutch hospitals and rehabilitation centers throughout the country. All eligible participants were initially screened by a physician. Inclusion criteria were diagnosis of PPS,¹⁵ age between 18 and 75 years, life expectancy >1 year, ability to cycle on a bicycle ergometer at an intensity of at least 25W, and capability of walking with or without walking aids. Exclusion criteria were use of psychotropic drugs or other psychiatric treatment, clinical depression, disabling comorbidity influencing the outcome parameters (including cardiopulmonary disease, epileptic seizures, and poorly regulated diabetes mellitus), respiratory insufficiency, cognitive impairment, and pregnancy. Both studies were approved

by the medical ethics committee of the University of Amsterdam, The Netherlands, and written informed consent was obtained from all participants.

Procedure

We collected data on demographic characteristics (age, sex, height, weight) and polio characteristics (age at acute polio, time since new symptoms, present walking distance). Furthermore, we determined muscle strength of the lower limbs by manual muscle testing according to the Medical Research Council Scale.¹⁶

Submaximal exercise test

Participants performed an incremental exercise test on a cycle ergometer^a with continuous recording of gas exchange variables using the COSMED K4b², a portable breath-by-breath gas analysis system.^b Heart rate was measured with a Polar RS400 heart rate monitor.^c The test protocol started with the measurement of resting energy expenditure during 3 minutes while sitting in a chair. The exercise test consisted of 3 minutes unloaded cycling after which the workload was increased by 10W every minute. Using this 1-minute step protocol is recommended for patients to avoid early termination of the test (because of sudden increases in work rate), and it results in a sufficient quantity of accumulated data.¹⁷ During the test, the individuals' feet were strapped to the pedals with toe clips and extra bands, if necessary. Criteria for stopping the test were the heart rate exceeding 80% of the estimated HRR, the pedal frequency dropping <60 revolutions per minute, or the participant's being unable to continue the test for any reason. The same criteria were used for participants using beta-blocking agents. However, if the RPE exceeded a score of 16 on the Borg Scale before these participants reached their target heart rate, the test was stopped. The HRR was defined as the difference between the maximal heart rate and the heart rate at rest. The maximal heart rate was estimated at 220 minus age,³ and the heart rate at rest was the mean value of the last minute of the 3-minute resting measurement. The protocol was completed with 3 minutes of unloaded cycling. At each work load and at the end of the exercise test, participants rated their perceived exertion on the Borg Scale (range, 6–20).¹⁸ Gas exchange and heart rate data were stored on a computer for offline analysis with the COSMED K4b² software.

Data analysis

Power output, heart rate, gas exchange values, and the RPE were determined from the highest achieved increment. Two independent experienced researchers determined the AT through visual inspection of the gas exchange plots using the V-slope method (fig 1).¹¹ In participants where the AT could be identified, power output, heart rate, gas exchange values, and the RPE were determined at the moment of the AT. Disagreements between the 2 researchers were discussed and resolved in a consensus meeting.

The relations between recommended target intensity based on current guidelines and the AT were visualized using plots. According to these guidelines, participants of the present study would have been recommended to start their training program at an intensity of approximately 40% to 60% estimated HRR or an RPE of 12.^{19,20} The heart rate corresponding to these intensities (40% HRR, 60% HRR, RPE of 12) was determined for every individual and was plotted against the heart rate attained at the AT.

List of abbreviations:

AT	anaerobic threshold
bpm	beats per minute
HRR	heart rate reserve
NMD	neuromuscular disease
PPS	postpolio syndrome
RPE	rating of perceived exertion

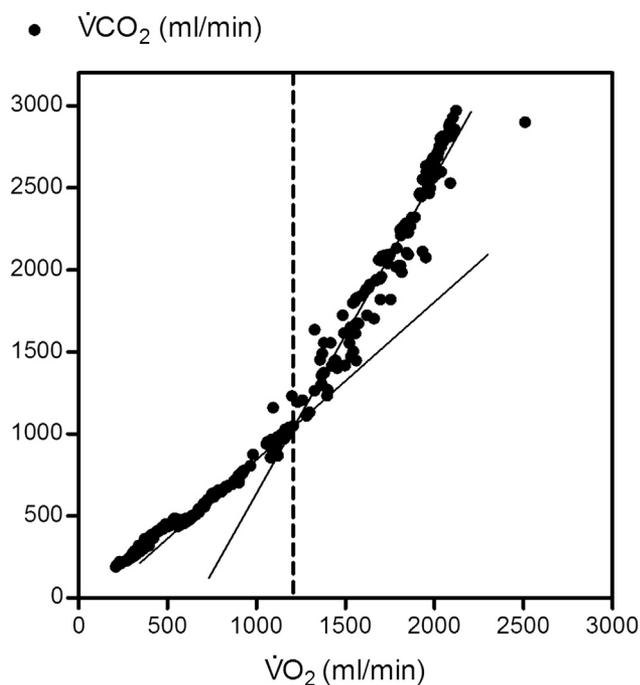


Fig 1 Gas exchange plot from the submaximal exercise test of a representative participant to illustrate identification of the AT. With the V-slope method, the $\dot{V}_{CO_2}/\dot{V}_{O_2}$ plot is used to identify the point at which the \dot{V}_{CO_2} starts to increase more rapidly than \dot{V}_{O_2} . The vertical dashed line represents the AT. Abbreviations: \dot{V}_{CO_2} , carbon dioxide production; \dot{V}_{O_2} , oxygen consumption.

Subsequently, we determined the proportion of individuals that would be recommended to train at an intensity below, at, or above the AT. We considered training intensity prescription to correspond to the AT if the recommended heart rate fell within a range of 10 beats per minute (bpm) around the heart rate attained at the AT (± 5 bpm). Participants using beta-blocking agents were not included in the HRR and AT relation.

Descriptive data were expressed as mean \pm SD (demographic data) or as median and range (polio characteristics). For normally distributed data, differences between the participants with AT and those without AT were analyzed with the Student *t* test; in the case of nonnormally distributed data, the Mann-Whitney *U* test was used. Dichotomized variables were analyzed with the Fisher exact test. Pearson correlation coefficients were calculated to examine the associations between the recommended heart rate based on current guidelines (40% HRR, 60% HRR, RPE of 12) and the heart rate attained at the AT. Systematic differences were analyzed with paired *t* tests. Statistical analysis was performed with SPSS software (version 20.0.0.1).^d An alpha level of .05 was used for all tests of significance.

Results

Study group

All 82 participants with PPS included in this study (33 men, 49 women; age range, 25–74y) performed the exercise test. Clinical signs of polio residuals in the lower extremities based on manual

Table 1 Participant characteristics

Characteristic	PPS (N=82)
Demographic data	
Sex (male/female)	33/49
Age (y)	59.3 \pm 8.0
Weight (kg)	75.9 \pm 13.1
BMI (kg/m ²)	26.4 \pm 3.8
Polio characteristics	
Age at acute polio (y)	2 (0–40)
Time since new symptoms (y)	15 (2–44)
Present walking distance*	
Indoors only (n)	1
Around the house (n)	25
Seldom further than 1km (n)	40
Regularly further than 1km (n)	16
Residual paresis in 1 leg/2 legs	57/23

NOTE. Values for demographic data are mean \pm SD, and values for polio characteristics are median (range); all other values are as otherwise indicated.

* 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).

muscle testing were found in all except 2 participants (table 1). Thirteen participants used beta-blocking agents.

Submaximal exercise test

Thirty-one participants reached the target heart rate of 80% of the estimated HRR. Eight participants, all using beta-blocking agents, reached the endpoint based on perceived exertion (>16 on the Borg Scale). All other participants (n=43) stopped the test because the pedal frequency dropped <60 revolutions per minute (table 2). None of the participants reported physical complaints in the days after the test.

Anaerobic threshold

The AT could be identified in 63 of the 82 participants (77%) and occurred at a mean power output \pm SD of 49 \pm 16W and at a mean heart rate \pm SD of 110 \pm 14 bpm (table 3). Expressed as a percentage of the estimated HRR, the AT occurred at a mean of 42% \pm 13% (range, 17%–73%).

No differences were found for demographic variables, beta-blocking agent use, and polio characteristics between the group of participants in whom the AT could be identified and the group without the AT. Participants without the AT stopped more often because they could no longer maintain the pedal frequency ($P<.05$). The power output during the final increment of the exercise test was significantly higher in the AT group than the group without AT (85 \pm 27W vs 62 \pm 23W, $P<.001$). Furthermore, oxygen consumption, minute ventilation, and the respiratory exchange ratio during the final increment were all significantly higher in the group of participants in whom the AT could be identified (see table 2). No significant difference was found regarding the RPE at the end of the exercise test between the 2 groups.

Table 2 Exercise parameters during the final increment of the exercise test and the reasons for stopping

Exercise Test Results	All (N=82)	AT (n=63)	No AT (n=19)	Mean Difference Between AT and No AT (95% CI)	P*
Exercise parameters (end of test)					
Power output (W)	80±28	85±27	62±23	24 (10 to 37)	≤.001
Peak heart rate (bpm)	134±19	136±18	128±20	8 (-2 to 18)	.114
Patients without beta blockers [†]	137±18	139±18	130±20	9 (-2 to 19)	.093
Oxygen consumption (L·kg ⁻¹ ·min ⁻¹)	19.1±4.7	19.8±4.2	17.10±5.6	2.70 (0.3 to 0.5)	.024
Minute ventilation (L/min)	51±16	54±16	39±13	15 (7 to 23)	≤.001
Respiratory exchange ratio	1.03±0.10	1.06±0.09	0.95±0.08	0.11 (0.06 to 0.15)	≤.001
Borg Scale	17±2	17±2	16±2	1 (0 to 2)	.098
Reasons for stopping					
Heart rate >80% HRR	31	26	5	NA	.289
RPE ≥16 [‡]	8	8	0	NA	.188
Revolutions per minute <60	43	29	14	NA	.040

NOTE. Values are mean ± SD or as otherwise indicated. There are missing data in heart rate recording for 4 AT and 1 no AT.

Abbreviations: CI, confidence interval; NA, not applicable.

* Student *t* test for exercise parameters and Fisher exact test for reasons for stopping.

[†] Heart rate values for patients without beta blockers (n=69; AT: n=52; no AT: n=17).

[‡] Only applicable to patients with beta blockers and not reaching a heart rate >80% HRR.

Recommended training intensity based on current guidelines compared with the AT

In cases of prescription based on an RPE, more individuals with PPS would have been recommended to train at an intensity corresponding to their AT than in cases of prescription based on the HRR (figs 2A, 2B, 3; table 4).

The mean heart rate corresponding to the 60% HRR was significantly higher than the mean heart rate at the AT (mean difference, 14.6±12.4 bpm; *P*<.001), whereas we found no systematic differences between mean heart rates corresponding to the 40% HRR and the AT (-2.9±11.9 bpm, *P*=.09) and between an RPE of 12 and the AT (-1.1±9.1 bpm, *P*=.365). Correlation coefficients between current guidelines and the AT were lower in cases of 40% HRR (*r*=.56, *P*<.001) and 60% HRR (*r*=.50, *P*<.001) than in cases of prescription based on RPEs (*r*=.86, *P*<.001).

Discussion

The present study demonstrates that the AT can be identified in most (77%) individuals with PPS with submaximal incremental

exercise testing. This finding is of importance because it implies that the AT can be assessed in most individuals while avoiding maximal exertion, which might provoke muscle complaints. Furthermore, for those individuals for whom it is not possible to determine the AT, our results suggest that exercise prescription should, preferably, be based on RPEs instead.

It appeared that almost half of the participants met 1 of the submaximal stopping criteria used. In this population, the AT could be identified in the vast majority (87%), implying that even though these participants could continue their exercise test, this was not necessary to determine the AT. It demonstrates that sufficient data points beyond the AT were obtained, which is necessary to identify the change in slope, indicating the AT, in the gas exchange plots. In 5 participants, however, the AT could not be identified despite reaching their target HRR. This finding may indicate that in these participants, the AT would have occurred at an intensity close to or above 80% HRR, hampering identification of a clear threshold. Another explanation is that their actual maximal heart rate was underestimated, and their exercise intensity did not reach the AT. Because the validity of the estimated age-related maximal heart rate for individuals can be questioned, it remains uncertain what the actual exercise stress for each participant was during the exercise test.²¹ Nevertheless, even though intensity levels might have been insufficient to determine the AT in some cases, the proportion of participants in which the AT was identified (77%) is comparable with results using the conventional method (72%) where all participants exercised until exertion.¹²

The absence of the AT in individuals with PPS (23%) may be related to reduced muscle function of the lower limbs, as indicated by the significantly lower power output during the final increment of the exercise test in this group compared with the group with the AT. However, other factors (eg, fear of physical complaints, not being accustomed to cycling, lack of motivation) probably caused some participants to stop the exercise test prematurely, despite having sufficient muscle strength.^{13,22} Further knowledge about the inability to identify the AT is essential for physical therapists in designing training programs. If this absence is caused by

Table 3 Exercise parameters at the moment of the AT

Exercise Parameters	AT (n=63)
Power output (W)	49±16
Heart rate (bpm)	110±14
Patients without beta blockers*	112±14
Oxygen consumption (L·kg ⁻¹ ·min ⁻¹)	14.10±2.40
Minute ventilation (L/min)	29±6
Respiratory exchange ratio	0.88±0.06
Borg Scale	12±2

NOTE. Values are mean ± SD. There is missing data for heart rate recording in 4 patients.

* Heart rate value for patients without beta blockers (n=52).

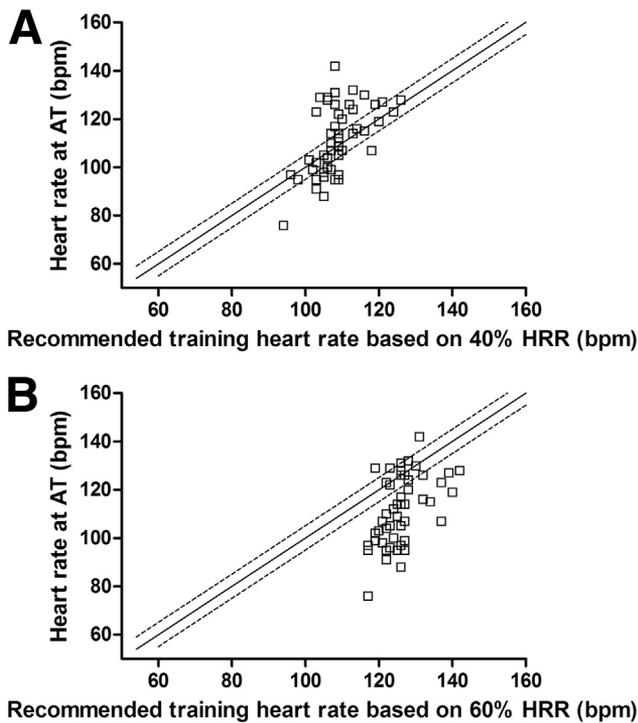


Fig 2 Heart rate corresponding to the 40% HRR (A) and 60% HRR (B) plotted against the heart rate attained at the AT for all individuals, except those using beta-blocking agents. The solid line represents the situation in which the recommended training heart rate based on the HRR exactly equals the heart rate attained at the AT. We considered training intensity prescription to correspond with the AT if the recommended heart rate fell within a range of 10 bpm around the heart rate attained at the AT (dashed lines represent +5 bpm (upper) and -5 bpm (lower), respectively).

reduced muscle functioning, other exercise modes may be considered for aerobic exercise training and testing. In other cases, adapting the testing procedure (eg, habituation sessions) may suffice to determine the AT.

Furthermore, our results indicate that current guidelines for training intensity prescription in PPS based on RPEs correspond better to the AT than prescription based on estimated HRR. From our results it appears that the recommended training intensity is above the AT in many individuals when prescription is based on the HRR, even in cases of 40% HRR (24%). Besides the fact that this is probably unnecessary to induce aerobic training effects,^{23,24} it may, for most individuals, be too exhausting to sustain these exercise intensities during training. This latter assumption is supported by our own experiences and earlier studies investigating the effectiveness of aerobic training in PPS. For example, in studies by Jones,²⁵ Kriz,²⁶ and colleagues, the training intensity was set at 70% to 75% of the HRR, which appeared unfeasible for several participants and had to be adjusted. The observation that the target intensity was apparently not appropriate for all individuals is corroborated by results from Kriz²⁶ who showed that the mean heart rate achieved during their training program represented only 50% of the HRR. Together our results indicate that based on current guidelines, the recommended intensity is overestimated in a substantial part of the individuals with PPS. Moreover, they confirm earlier reports emphasizing the need for training programs tailored to the individual's aerobic capacity,

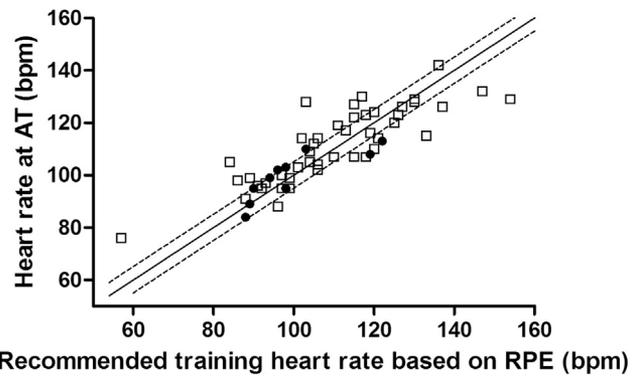


Fig 3 Heart rate corresponding to an RPE of 12 plotted against the heart rate attained at the AT for individuals with (black circles) and without beta-blocking agents (open squares). The solid line represents the situation in which the recommended training heart rate based on RPE exactly equals the heart rate attained at the AT. We considered training intensity prescription to correspond with the AT if the recommended heart rate fell within a range of 10 bpm around the heart rate attained at the AT (dashed lines represent +5 bpm (upper) and -5 bpm (lower), respectively).

instead of prescription based on a fixed percentage of the HRR for a group of patients.²⁷

Even though intensity prescription based on RPEs corresponds better to the AT than the AT based on the HRR, it is important to realize that, for part of the individuals with PPS (19%), recommended target intensity is still above their AT. However, most will have a recommended intensity at or near the AT. This close relation between RPEs and the AT is consistent with the literature, showing that although there is clearly some variation between individuals, the perception of work at the AT is quite similar among subjects within the same population. This makes it a useful alternative for training intensity prescription.²⁸⁻³⁰

Study limitations

A limitation to our findings is that we selected individuals who could cycle on an ergometer. Therefore, despite the relatively large sample size, generalizability of the study to all survivors of polio may be compromised. Another limitation is that the AT was not identified in some of the individuals. As a consequence, it is unclear whether results that were found in the group of individuals in which we identified the AT are applicable to the group of individuals without AT as well.

Table 4 Proportion of individuals that would be recommended to train at an intensity below, at, or above their AT

Current Guidelines	Below AT (%)	AT (%)*	Above AT (%)
40% HRR	35	41	24
60% HRR	6	18	76
RPE of 12	26	55	19

* We considered training intensity prescription based on current guidelines to correspond to an intensity of the AT if the recommended heart rate fell within a range of 10 bpm around the heart rate attained at the AT (± 5 bpm).

Conclusions

Submaximal incremental exercise testing can be used for assessment of the AT in most individuals with PPS who can cycle on an ergometer and enables physical therapists to better individualize exercise intensity for aerobic training. If the AT cannot be identified (eg, because gas analysis equipment is not available), training prescription should, preferably, be based on RPEs. A next step is to study the feasibility of training at the AT in individuals with PPS and in other NMDs.

Suppliers

- a. Lode BV, Zernikepark 16, 9747 AN Groningen, The Netherlands.
- b. COSMED Srl, Via dei Piani di Monte Savello 37, PO Box 3, Pavona di Albano, Rome, I-00040, Italy.
- c. Polar Electro Oy, HQ Professorintie 5, FIN-90440 Kempele, Finland.
- d. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.

Keywords

Anaerobic threshold; Exercise; Exercise test; Neuromuscular diseases; Postpoliomyelitis syndrome; Rehabilitation

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