**Workstation 1: Exercise training: linear vs non-linear training**

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**AIMS**
- To illustrate how and when linear and non-linear exercise training are needed.
- How to prescribe a non-linear exercise training programme
- To discuss the monitoring tools required during non-linear exercise training

**SUMMARY**

**Introduction**

The 2006 ATS/ERS Guidelines on Pulmonary Rehabilitation (Nici et al. Am J Resp Crit Care Med 2006), define pulmonary rehabilitation (PR) as “... an evidence-based, multidisciplinary, and comprehensive intervention for patients with chronic respiratory diseases who are symptomatic and often have decreased daily life activities. Integrated into the individualized treatment of the patient, pulmonary rehabilitation is designed to reduce symptoms, optimize functional status, increase participation, and reduce health care costs through stabilizing or reversing systemic manifestations of the disease.” One of the goals of PR in COPD is to ameliorate exercise intolerance (the inability to successfully sustain the work rates required for successful task completion), the aetiology of which involves factors such as impaired lung mechanics (increased ventilatory, airflow and volume expansion demands that encroach on reduced limits of respiratory-mechanical performance) leading to exertional dyspnoea, arterial desaturation, deconditioning and cachexia. Exercise training, combining endurance and resistance elements, is therefore a key component of PR programmes for COPD patients, because of its potential to engender systemic gains such as: increased capillarity and aerobic-enzyme concentrations in the involved muscles; faster pulmonary gas exchange and ventilatory kinetics when moving between different work rates; a decreased degree of lactic acidosis at a given work rate; and decreased ventilation and breathing frequency leading to reduced dynamic hyperinflation and reduced dyspnoea.

Central to the structure of the PR-based exercise training programme is the recognition that the outcome effects will be specific to the activity modality employed (i.e. task specificity) and therefore the muscles utilised (including the heart) and the muscle fibres recruited (with the potential for collateral benefit). Endurance training on an ergometric device (which allows accurate monitoring of training load) comprises the core component, typically cycling or walking. However, other exercise formats and modalities have variously been demonstrated also to improve exercise tolerance, e.g. interval training, strength training, upper limb training, leisure walking, Nordic walking, water-based training and transcutaneous neuromuscular electrical stimulation.

It has been established practice for many years the 1998 American College of Sports Medicine (ACSM) cardiopulmonary fitness guidelines for healthy individuals be applied also to exercise training in COPD patients (Gosselink et al 1997; American Thoracic Society 1999): i.e. supervised exercise (e.g. cycling, treadmill walking) should be performed for 3-5 days per week at an intensity between 40 to 85% of the oxygen uptake reserve (difference between resting and peak oxygen uptake) or heart rate reserve (difference between predicted and actual maximal heart rate) for more than 20 minutes (as a practical expedient ~60-80% of peak work rate on a ramp exercise test), continuously or as a series of exercise intervals interspersed with rest (American College of Sports Medicine 1996).
The success or otherwise of endurance exercise training in improving exercise tolerance in COPD patients varies, likely reflective (in part, at least) because of variations in symptomology, such as limb muscle weakness (e.g. hyperinflation, hypoxaemia, inactivity, inflammation) and nutritional status (e.g. nutritional depletion, low fat-free mass). The inclusion of resistance training is one element that has become recognized as a strategy for improving exercise outcomes not only in healthy individuals (American College of Sports Medicine 2009) but also in COPD patients. For example, resistance training can be beneficial in improving peripheral muscle function in COPD patients having reduced skeletal muscle mass and/or strength. Also, COPD patients with severe respiratory impairment have been demonstrated to benefit from resistance training of small muscle groups (e.g. arms) which, not being limited by central cardiorespiratory to the extent that larger lower-limb locomotor muscles are, serves to alleviate the impact of ventilatory limitation and exertional dyspnoea. Traditional resistance training programmes are based on principles of specificity, variation and progressive overload through factors such as: sequence and range of exercises, intensity, volume (i.e. number of sets, repetitions/set), movement velocity, rest interval between sets and (American College of Sports Medicine 2009). Current guidelines recommend training sessions comprising 2-4 sets, each of 6-12 repetitions, at intensities ranging from 50 to 85% of the one-repetition maximum (1-RM), i.e. the maximum weight that can be lifted once. (American Thoracic Society/European Respiratory Society 2006).

Despite these several advances, exactly how an exercise training programme for the COPD patient undergoing PR should be optimized (i.e. with regard to exercise format, intensity and duration) relative to the requirements of the individual COPD patient remains a significant challenge.

**Linear and Nonlinear Exercise Training**

Central to traditional PR-based exercise training programmes of the kind described above is a format with a fixed exercise modality, and a progressive increase in training volume accomplished via increases in exercise intensity and exercise duration. The process of altering one or more programme variables over time so that the training ‘stimulus’ remains effective is termed variation or “periodization”. Linear periodization models begin with high-volume/low-high intensity training and progress towards low-volume/high-intensity training.

Nonlinear periodized exercise (NLPE) training programmes, which are now widely used in the athletic setting, differ fundamentally from linear models. Thus, individualized changes in training intensity, exercise duration, recovery duration and exercise type are made considerably more frequently, even as frequently as between training sessions; with the goal of attaining different adaptations of the neuromuscular system within the same training phase, but not within the same session. The advantage of nonlinear models is that individual adaptation is maximized, overtraining is prevented and an optimal training effect is attained (American College of Sports Medicine 2009). For example, it has been demonstrated that both linear and nonlinear periodized resistance training programmes result in greater strength gains than non-periodized programmes, with evidence supporting even greater strength gains with daily nonlinear periodization.

The principles of NLPE have recently been applied to patients with severe COPD (Klijn et al 2013; Sant’Anna et al 2013). Klijn et al reported greater improvements in endurance time on a constant-workrate cycle ergometer test (at 75% of maximum work rate from a ramp exercise test) and health-related quality of life, compared with a traditional endurance and progressive resistance exercise training programme, whether patients were depleted or nondepleted with respect to fat-free mass. Endurance training gains were achieved with fewer sessions, and reduced total volume of endurance training and exercise time (with a slight increase in exercise intensity); also, progression was more rapid. Resistance training gains were achieved with a greater number of repetitions performed at a lower exercise intensity. And as overall, symptom scores were lower, NLPE may have the potential to benefit patients with significant ventilatory limitation, and to reduce the incidence of non-responders to PR.

**Design of Nonlinear Periodized Exercise Training Programmes**
The novelty of the NLPE training format in the PR context means that there are no published guidelines or evidence base against which to set principles of optimal programme design or outcome evaluation.

**Assessment**

Current guidelines recommend: “Before starting an exercise training program, an exercise assessment is needed to individualize the exercise prescription, evaluate the potential need for supplemental oxygen, help rule out some cardiovascular comorbidities, and help ensure the safety of the intervention.” (American Thoracic Society/European Respiratory Society 2013).

Selection of the exercise assessment for individualizing the exercise prescription is important, with the “gold standard” test being the symptom-limited ramp (or incremental) exercise test, throughout which work rate increases at a constant rate (e.g. American Thoracic Society/American College of Chest Physicians 2003; Wasserman et al 2012). This test, conducted on a cycle ergometer or a motorized treadmill, imposes a smooth gradational stress which spans the patient’s entire tolerance range. When coupled with comprehensive breath-by-breath cardiorespiratory and gas exchange monitoring (American Thoracic Society/American College of Chest Physicians 2003; Porszasz et al 2007; Wasserman et al 2012), this allows (a) the limits of system function to be established; (b) the effective operating range to be defined; (c) potential causes of exercise intolerance to be identified; (d) the normalcy of responses with regard to related physiological functions and to reference populations to be evaluated; and (f) a frame of reference for change with respect to interventions such as training to be provided, e.g. the design of the high-intensity constant-workrate cycle ergometer test – the duration of which has been shown to be particularly sensitive to interventional change (e.g. American Thoracic Society/American College of Chest Physicians 2003; ERS 2016).

Thus, baseline assessment in the Klijn NLPE study (Klijn et al 2013) prior to entry into the main training phase included; resting pulmonary function and subdivisions of lung volume (body plethysmography); fat-free mass (bio-impedance analysis); a high-intensity constant-workrate cycle ergometer test at 75% of maximal work rate; maximal isotonic strength testing (1-RM); and health-related quality of life (Chronic Respiratory Questionnaire). Patient-specific deficits (e.g. low fat-freemass, anxiety) were taken account of in programme design.

**Training**

The Klijn NLPE study (Klijn et al 2013) comprised a 10-week NLPE supervised training programme, three times a week on alternate days. It included endurance training on a cycle ergometer and resistance training on standard isotonic strength equipment (leg press, bilateral leg extension, pull down, chest press) (Table 1). The programme characteristics were varied frequently for both endurance and resistance training elements (Tables 2 and 3). To optimize physiological adaptation, resistance training in a given session addressed the same energy system (aerobic or anaerobic) as the endurance training; e.g. aerobic cycle training was combined with high-volume/low-intensity resistance training, while anaerobic cycling was combined with low-volume/moderate-to-high intensity resistance training (Table 4).

**Progression**

Current PR guidelines recommend the use of symptom scores to adjust training load, with a Borg score of 4 to 6 for dyspnoea or fatigue usually being a reasonable target. In their NLPE training programme, Klijn et al. expanded this criterion: “... to ensure optimal progression the therapists in the study were responsible for supervising endurance duration, repetition range, loads and rest periods. Evaluation of exercise-induced dyspnea, exercise-induced fatigue and sense of effort with the category-ratio Borg scale was included immediately following exercise completion during the rest phases between sets and exercises. Symptom ratings were primarily used to guide adjustment of exercise ...” (Klijn et al 2013, online supplement).
**Outcome measures**

The primary outcome measures used in the Klijn study (Klijn et al 2013) were endurance time on a high-intensity constant-workrate cycle ergometer test (at 75% of maximum work rate from a ramp exercise test) and health-related quality of life, with secondary outcomes including leg-press strength, body mass index, and fat-free mass index (FFM/height²) (Klijn et al 2013).
TABLE 1. GENERAL OUTLINE OF NONLINEAR PERIODIZED EXERCISE PROGRAM DESIGN AND ADAPTATIONS (Klijn et al 2013)

<table>
<thead>
<tr>
<th>Program design</th>
<th>Description</th>
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</table>
| Physiological and psychological adaptation phase (Base training). First two to three training sessions—aerobic cycle exercise, two to three series, 3–5 min, 50–60% Wmax and resistance exercise, two series (12–15 repetitions) 40–50% 1-RM. Progression: introduction of anaerobic higher-intensity cycle exercise (three to five series, 2–3 min, 65–70% Wmax) and high repetition-volume leg press (>20 repetitions). Daily, weekly, or biweekly rotation of cycle work phase intensity and repetition zones. Phase of recovery or taper to reduce accumulated training fatigue. Reduction of cycle and resistance training volume and number of sessions during the last week before exercise testing, while maintaining training intensity. Progressive overload Criteria for adaptation and progression through the training program Cycle exercise: Prolonging the aerobic work phase: two to three series of 6–8 min as tolerable* Prolonging the anaerobic work phase: two to three series, 5 min Increasing the anaerobic work intensity: 70–80% Wmax RT: Increasing the repetition-volume of the primary RT exercise (leg press) Increasing the intensity (repetition-load) within the 1-RM range

<table>
<thead>
<tr>
<th>Individual patient characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with low FFMi perform only resistance exercises during the first training period in order to improve muscle function or muscle efficiency relative to muscle mass. In case of severe oxygen desaturation on exertion ([SpO₂], 86%) despite oxygen therapy, transient pre-exercise dyspnea or fatigue, exercise-induced fear of dyspnea†, and low baseline or 6-wk CWT (&lt;8 min) only RT protocols are used temporarily. Cycle protocols are used as tolerated* to apply training specificity: three to five series, 2–3 min, 65–70% Wmax. Patients with higher baseline or 6-wk CWT duration (&gt;8–10 min) are able to endure longer duration and higher intensity exercise. Prolonging the anaerobic work phase: two series, 7 min Prolonging the aerobic work phase: two series, 10 min, 50–60% Wmax Increasing anaerobic work intensity: 6–10 series, 1–2 min, 85–95% Wmax Increasing aerobic work intensity: 4 x 4 min, 80–95% Wmax and 3 min active recovery, 50% Wmax.</td>
<td></td>
</tr>
</tbody>
</table>

* Low symptom scores with respect to the degree of threat imposed by these symptoms. † High degree of threat or anxiety to cycle exercise.

Definition of abbreviations: 1-RM = one-repetition maximum; CWT = constant work rate cycle test; FFMi = fat-free mass; RT = resistance training; SpO₂ = oxygen saturation as measured by pulse oximetry; Wmax = maximal work rate.
Table 2. Repetition training zones for resistance training in nonlinear periodized exercise (Klijn et al 2013)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Repetition Range</th>
<th>Sets</th>
<th>1-RM Range</th>
<th>Rest (min)</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>≥20</td>
<td>1-2</td>
<td>30–40%</td>
<td>1</td>
<td>Muscle endurance</td>
</tr>
<tr>
<td>Low</td>
<td>12–15</td>
<td>2</td>
<td>40–50%</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>8–10</td>
<td>3-4</td>
<td>50–65%</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>4–6</td>
<td>4–5</td>
<td>70–80%</td>
<td>2–3</td>
<td></td>
</tr>
<tr>
<td>Very high</td>
<td>1–3</td>
<td>4–5</td>
<td>85–95%</td>
<td>3–4</td>
<td>Muscle strength</td>
</tr>
</tbody>
</table>

*Definition of abbreviation:* 1-RM = one-repetition maximum. Repetition ranges emphasizing a specific resistance training outcome with number of sets, percentage 1-RM range and rest interval between sets. Repetition training zones allow a patient to complete a set without going to muscular failure (e.g., not being able to perform another full repetition). Based on Kraemer and Fleck (11).

Table 3. Cycle exercise training protocols in nonlinear periodized exercise (Klijn et al 2013)

<table>
<thead>
<tr>
<th>No. of Series</th>
<th>Work Phase</th>
<th>Rest Phase</th>
<th>% Wmax</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–3</td>
<td>3–10 min</td>
<td>1–3 min</td>
<td>50–60</td>
<td>Aerobic</td>
</tr>
<tr>
<td>4</td>
<td>4 min</td>
<td>1–3 min</td>
<td>80–90</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 min active recovery</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>30 s</td>
<td>30 s</td>
<td>100–120</td>
<td></td>
</tr>
<tr>
<td>4–8</td>
<td>2–7 min</td>
<td>2–5 min</td>
<td>65–80</td>
<td>Anaerobic</td>
</tr>
<tr>
<td>6–10</td>
<td>1–2 min</td>
<td>2–3 min</td>
<td>85–95</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5–10 min</td>
<td>—</td>
<td>50</td>
<td>Compensation</td>
</tr>
</tbody>
</table>

*Definition of abbreviation:* % Wmax = percentage of maximum work rate attained during cardiopulmonary exercise test.

Aerobic and anaerobic interval cycle protocols used during training in nonlinear periodized exercise groups. The primary energy system addressed during cycling depends on the duration and intensity of the work phase, and the duration of the rest phase. The appropriate duration and intensity is determined by the deliberation of the individual patient deficiencies and needs, and the position in the overall training process. Compensation cycling (50% Wmax) is used at the end of anaerobic training to supplement recovery (8).

Table 4: Combined cycle and resistance training in nonlinear periodized exercise training (Klijn et al 2013, on-line supplement)
Conclusion

The development of PR-based NLPE training programmes for COPD patients is at a very early stage. Whether such programmes will come to mirror their athletic counterparts for COPD patients with diverse symptomology in maximizing individual adaptation, preventing overtraining with attainment of an optimal training effect (American College of Sports Medicine 2009) warrants systematic and comprehensive evaluation. In particular, attention needs to be given to issues such as:

(a) the work-rate selection criteria for the high-intensity constant-workrate test – In interventional studies, it is standard practice at present to use a relatively high and fixed percentage of the maximum work rate achieved on a ramp exercise test (ERS 2016). This requires account to be taken of the relationship between maximum work rate and peak oxygen uptake which, because of the response kinetics inherent in the latter, will vary with the workrate incrementation rate on the ramp test (e.g. American Thoracic Society/American College of Chest Physicians 2003; Wasserman et al 2012). Furthermore, a given percentage of the maximum work rate does not, a priori, conform to the same exercise intensity for different patients; i.e. in some it may be above the lactate threshold, while in others it may be below, with significant consequences for exercise tolerance (e.g. American Thoracic Society/American College of Chest Physicians 2003; Wasserman et al 2012).

(b) training progression monitoring – In the athletic setting, it is conventional practice to take account of blood [lactate] as a measure of metabolic stress or a surrogate variable such as heart rate. The reliance simply on perceptual ratings in the PR setting is unlikely to be as robust, although its practical value is well established (i.e. in terms of patient compliance and resource requirements for programme delivery).

RECOMMENDED READING

Physiology


Pathophysiology


Principles of Exercise Training

Principles of Pulmonary Rehabilitation


Assessment in Pulmonary Rehabilitation


EVALUATION

1. Compared to traditional (progressive) exercise training programmes, non-linear periodized exercise training programmes:
   a. allow patients to supervise their own training
   b. minimize the likelihood of overtraining
   c. require longer exercise-training periods
   d. begin with high-volume/low-high intensity training and progress towards low-volume/high-intensity training.

2. Which test would you use to calculate the training work rates for a non-linear exercise training programme?:
   a. Six-minute walk test
   b. Incremental cycle-ergometer or treadmill exercise test
   c. Incremental shuttle test
   d. High-intensity cycle-ergometer or treadmill constant work-rate test

3. What indices could you use to assess progression for a non-linear exercise training programme?:
   a. duration of a high-intensity constant-workrate test
   b. breathing frequency
   c. dyspnoea
   d. FEV₁