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REVIEW

Targeting exercise intensity and aerobic training to improve outcomes in Parkinson's disease

Tone Ricardo Benevides Panassollo[1] · Grant Mawston[1] · Denise Taylor[1] · Sue Lord[1]

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Abstract

Aerobic training is popular for people with Parkinson's disease (PD) given its potential to improve aerobic capacity, relieve symptoms, and to stabilise disease progression. Although current evidence supports some of the assertions surrounding this view, the effect of exercise intensity on PD is currently unclear. Reasons for this include inconsistent reporting of exercise intensity, training regimes based on general guidelines rather than individualised physiological markers, poor correspondence between intended exercise intensities and training zones, and lack of awareness of autonomic disturbance in PD and its impact on training regimes and outcome. We also consider the selective effect of exercise intensity on motor symptoms, function and disease progression. We review aerobic training protocols and recent guidelines for people with PD, highlighting their limitations. Considering this, we make suggestions for a more selective and discerning approach to aerobic training programming.

Keywords Parkinson's disease · Exercise intensity · Training zone · Aerobic capacity · Autonomic dysfunction

Abbreviations

PD	Parkinson's disease
UPDRS	Unified Parkinson's disease rating scale
CI	Chronotropic incompetence
CPET	Cardiopulmonary exercise testing
HR	Heart rate
HRmax	Maximum heart rate
HRR	Heart rate reserve
VO2peak	Peak oxygen consumption
VT1	First ventilatory threshold
VT2	Second ventilatory threshold
WR peak	Peak workload
RPE	Rating of perceived exertion
MIIT	Moderate interval intensity training
HIIT	High intensity interval training
6MWT	6-Minutes walking test
TUG	Timed up and go
ACSM	American College of Sports Medicine

Introduction

Physical exercise is critical to the management of Parkinson's disease (PD) and is tailored according to individual needs as the disease progresses [1, 2]. The overarching goal of exercise is to enhance physical performance, health and wellbeing through an incremental increase in energy expenditure [3, 4]; a goal that in recent years has focused on the selective and critical role of aerobic training as a popular form of exercise in PD with trials evaluating its impact [5, 6]. There is also evidence to suggest that aerobic training at higher intensities may afford neuroprotection through stabilising motor symptoms and delaying disease progression. Although this theory is mainly supported by animal models, recent and ongoing studies suggest the evidence base is starting to expand [6–9].

Recent reviews report a positive effect of aerobic training on PD [10–13]. Less well understood is the specific effect of level of intensity on aerobic performance, motor symptoms and function, and whether protocols could be targeted more effectively to improve outcomes. Protocols very often follow training zones from general guidelines (e.g., American College of Sports Medicine (ACSM)) that do not take into account individualised responses to training regimes [14, 15]. These guidelines incorporate exercise intensity thresholds based on a percentage of maximal physiological

✉ Tone Ricardo Benevides Panassollo
tone.panassollo@autuni.ac.nz

[1] School of Clinical Sciences, Auckland University of Technology, Auckland, New Zealand

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measures such as maximum heart rate (%HRmax) and heart rate reserve (%HRR), obtained from maximum exercise tests or age-predicted equations. Subjective measures of intensity (e.g., rating of perceived exertion (RPE) scale) are also used [4]. A second issue is that the level of exercise intensity actually attained during aerobic training does not always align with the intended training zone which is particularly relevant if autonomic dysfunction is present given that it alters the assessment of metabolic and cardiac function [16, 17]. Finally, aerobic protocols often lack clarity around specific goals of training.

The aim of this review is to appraise exercise intensity as a key component of aerobic training with respect to aerobic capacity, functional performance, and motor symptoms in PD. We identify challenges associated with the implementation of high-intensity training and address the potential impact of impaired heart rate (HR) response on exercise intensity prescription. We limit our review to aerobic training protocols using cardiopulmonary exercise testing (CPET) to evaluate changes in aerobic capacity, due to its precision in capturing the physiological response to incremental exercise.

Method

The search strategy for this narrative review was not systematic, given the nature of the narrative approach. We conducted searches on the following databases: Scopus, Medline via EBSCO, and Google Scholar. The key search terms used were Parkinson's disease, aerobic exercise, aerobic training, aerobic capacity, peak and maximum oxygen consumption (VO2peak and VO2max), cardiopulmonary exercise testing (CPET), graded exercise test, blunted heart rate (HR), impaired autonomic nervous system, chronotropic incompetence (CI), and dysautonomia. We also checked all references of the papers we cited to ensure we had optimal coverage of the literature. We limited our review to aerobic training protocols that have used CPET to evaluate changes in aerobic capacity. In our search, we did not identify any articles evaluating HR responses in people with PD with CI. Therefore, unpublished CPET data conducted in our lab from 13 PD subjects with and 15 without CI were used to highlight the differences in HR responses and attained training zones between these two groups.

Terminology and scope of the review

We define exercise intensity as the amount of physical effort, quantified as a percentage of an individual's maximal physiological and clinical response to exercise [3, 18]. Training volume is defined as the product of duration (time per session) and frequency of training per week [18]. For consistency we use the term peak oxygen consumption (VO2peak) to represent the highest value attained during CPET to describe maximum aerobic capacity, instead of maximum oxygen consumption (VO2max) which requires a physiological response known as a plateau that proves challenging to be elicited within a clinical population [4, 19]. Whilst training volume and exercise modality are both important features of aerobic training, we do not consider them in detail in this review. However, we do comment on their application and efficacy where relevant.

Classification of exercise intensity and training zones

Studies evaluating the impact of exercise intensity in PD commonly apply aerobic protocols that reflect the ACSM *five training zones* classification [14, 20–22]. These training zones (Table 1) are typically defined as a percentage of maximal physiological or clinical measures of exercise intensity and vary from very light to near maximal intensity [4]. The term 'high intensity training zone' is frequently reported in the literature but not included in the ACSM classification. However, there is general agreement that high-intensity aerobic training elicits exercise intensities above 85% HRmax, 85% VO2peak, or 80% HRR [23–26] which approximate the higher end of the 'vigorous' and 'near maximal' training zones from the ACSM classification.

A second approach to classifying exercise intensity is the *threshold zone classification*, which is based on personalized physiological measures (first (VT1) and second (VT2) ventilatory thresholds) obtained from CPET [27, 28]. One advantage of the threshold zone classification over the ACSM classification is that it provides a comparable level of metabolic stimulus needed for a training effect across a population that vary in fitness levels [15]. In the threshold zone classification, light intensity reflects workload and physiological measures (e.g., HR, oxygen consumption) below VT1, whereas moderate intensity represents these measures between VT1 and VT2, and high intensity above VT2 [29–32]. The threshold zone classification may reproduce a more individualised and accurate classification of exercise intensity compared to the five training zones [27, 28].

Table 1 The five-zone exercise intensity classification adapted from the American College of Sports and Medicine [4]

	Zone 1 Very light	Zone 2 Light	Zone 3 Moderate	Zone 4 Vigorous	Zone 5 Near maximal
HRR (%)	< 30	30–39	40–59	60–89	≥ 90
HRmax (%)	< 57	57–63	64–76	77–95	≥ 96
VO2peak (%)	< 37	37–45	46–63	64–90	≥ 91
RPE	< 9	10–11	12–13	14–17	≥ 18

HRR heart rate reserve: *HRmax* maximum heart rate: *VO2peak* peak oxygen consumption: *RPE* Rating of perceived exertion

Studies show that aerobic training protocols based on the threshold zone classification yield greater improvements in VO2 peak compared with protocols that use %HRmax or %HRR, suggesting it is a more responsive metric [15, 33–35]. A study by Weatherwax et al., [33] illustrates this point. They found that 100% of healthy individuals aged between 30 and 75 year who used a threshold zone for training were classified as positive responders (change in VO2peak > 4.7%). By contrast, only 60% of those in the control group, who trained based on %HRR, were classified as positive responders. Although the threshold zone is widely applied in sports performance [18, 36] and more recently in cardiac rehabilitation [28, 37], the aerobic training protocols included in this review (Table 2) do not use VT1 and VT2 to prescribe exercise intensity despite using CPET to measure aerobic capacity. Instead, the percentage of maximum values of physiological measures (e.g., %HRmax and %VO2peak) obtained from CPET or age-predicted equations are used. There are arguments for and against the different approaches, with a recent review providing more insights on this issue [38]. Overall, our own view is to encourage the use of threshold zones to set intensity if CPET is available.

Training improves aerobic capacity (VO2 peak)

Aerobic training protocols vary in their description of exercise intensity, training volume, and exercise modality. For consistency, we used the ACSM classification (Table 1) to categorize training zones rather than the classification reported in each publication by aligning the measures reported (e.g., HRR, HRmax, VO2peak) with the relevant training zone. Aerobic protocols are grouped into continuous and interval training and a full description of all aerobic training protocols is presented in Table 2.

Continuous training protocols

Continuous aerobic training, defined as continuous exercise without active or passive recovery is the most common type of protocol for PD, with studies reporting a wide variation in both intensity and volume. Both moderate and vigorous intensities yield improvements in VO2peak, however, to optimise outcome it may be necessary to reach a minimum volume of training such as that described by the ACSM (150 min of moderate or 75 min of vigorous aerobic training per week) [4].

Schenkman et al. [39], reported no significant improvement in VO2peak in 45 PD participants after exercising 3–4 times per week for 30 min per session for 26 weeks, at an average intensity of 65.9% HRmax (moderate training zone – ACSM). Conversely, Shulman et al., [22] reported an improvement of around 6% in VO2peak in 22 PD participants exercising at 40–50% HRR (moderate training zone -ACSM) in a training protocol that incorporated a comparatively higher weekly volume of training (50 min per session, 3 × per week for 12 weeks).

Gains in aerobic capacity from vigorous intensity protocols (77–95% HRmax/60–89% HRR—ACSM) also vary considerably in people with PD. Participants from a study by Sacheli et al., [41] improved their VO2peak by approximately 22%, while participants from Shulman et al., [22] who also exercise at a vigorous intensity zone, improved their VO2peak on average of 7%, despite participants having similar baseline VO2peak values. The difference in aerobic fitness findings between these two studies may be due to the way in which exercise intensity and training volume were prescribed [18, 38, 48].

The protocol from Sacheli et al., [41] consisted of 3 sessions of bike training (30–50 min) per week for 12 weeks, with participants exercising at a workload relative to 60–80% VO2peak attained during CPET, representing moderate to vigorous training zone (Table 1). Exercise intensity and duration were increased after every third session. The total volume of training was high (90–150 min of exercise) at the target intensity. Participants from Shulman et al., [22] had the same length of training as Sacheli et al., [41] (3 × per week for 12 weeks), but exercised at a lower training volume. Exercise duration increased progressively from 15 to 30 min by 5 min every two weeks. Exercise intensity also increased progressively (from 40–50% HRR to 70–80% HRR) by adjusting treadmill speed and inclination. The total volume of training from this protocol varied from 45 to 90 min of exercise, but it is unclear whether training volume was targeted to intensity.

Taken together, these studies suggest that vigorous-intensity aerobic protocols potentially promote greater improvement in VO2peak compared with moderate-intensity protocols, but differences in the volume of training at the target exercise intensity will also impact this.

Interval training protocols

The ability to exercise continuously for a long period of time at high intensities is limited [3, 18]. Interval training protocols intersperse a work phase of moderate or high intensity with a recovery phase of lower intensity or passive recovery to offset this. Moderate-intensity interval training (MIIT) uses bursts of moderate-intensity whilst high-intensity interval training (HIIT) uses bursts of high intensity during the 'work phase' of the training protocol [4, 25, 49]. MIIT is better tolerated for beginners and used as a progression to HIIT protocols if required [49], bearing in mind that longer durations of the work phase are required to produce a training effect. A recent study that applied an MIIT protocol in 13 sedentary PD participants reported a 30.49% increase in VO2peak after 8

Table 2 Description of Parkinson's disease studies protocols

References	Demographic (SD)	Study protocol	Exercise intensity derived	Frequency and duration (Exercise time)	Week volume
Demonceau et al. [20]	N 16—H&Y I-III Age 65 (8)	Mix of continuous and HIIT—50–80% WRpeak—bicycle	50–80% of WRpeak	12 weeks of 30–45 min 2–3 × per week	135 min
Schenkman et al. [39]	N 43 – H&Y I-II Age 64 (9) N 45 – H&Y I-II Age 63 (10)	High intensity 80–85% HRmax-treadmill Moderate intensity 60–65% HRmax treadmill	80.2% HRmax 65.9% HRmax	26 weeks of 30 min 4 × per week 26 weeks of 30 min 4 × per week	120 min 120 min
Uc et al. [40]	N 21 – H&Y I-III Age 67.6 (7.5) N22—H&Y I-III Age 64.7 (5.2)	70–80% of estimated HRmax continuous—walking 80–90% of estimated HRmax HIIT—walking	71.1% (7.8) HRmax 69.2% (6.4) HRmax	24 weeks of 15–45 min 3 × per week 24 weeks of 15–45 min 3 × per week	135 min 135 min
Sacheli et al. [41]	N 20 – H&Y I-III Age 66.7 (5.98)	60–80% VO2peak—bicycle	60–80% VO2peak Relative to WRpeak	12 weeks of 30–50 min 3 × per week	150 min
Kurtais et al. [42]	N 12 – H&Y 2.5 (0.7) Age 63.8 (10.6)	70–80% of HRmax -treadmill	Not reported	6 weeks of 40 min 3 × per week	120 min †
Shulman et al. [22]	N 23 –H&Y II-III Age 66.1 (9.7) N 22 –H&Y II-III Age 65.8 (11.5)	70–80% of HRR treadmill 40–50% of HRR treadmill	Not reported Not reported	12 weeks of 30 min 3 × per week 12 weeks of 50 min 3 × per week	90 min 150 min
Harvey et al. [43]	N 16 – H&Y I-III Age 55 to 80	HIIT at ≥ 85% of HRmax—Resistance circuit training	≥ 85% of HRmax	12 weeks of 4 × of 4 min on × 3.5 min off. 3 × per week- Total 16 min per session	48 min ‡
Van der Kolk et al. [21]	N 65 – H&Y I-II Age 59.3 (8.3)	50–80% of HRR – bicycle	57.0% (9.6) HRR	24 weeks of 30 min 3 × per week	90 min
Penko et al. [44]	N35 – H&Y II-III Age 63 (8) N35 – H&Y II-III Age 61 (9)	60–80% HRR bicycle 60–80% HRR bicycle	67% ± 11 HRR 70% ± 10 HRR	8 weeks of 40 min 3 × per week 8 weeks of 40 min 3 × per week	120 min 120 min
Mavrommati et al. [45]	N 37 – Age 65 (7) H&Y – not reported	55–85% of estimated HRmax mix modality	Not reported	24 weeks of 30 min 2 × per week	60 min
Collett et al. [46]	N 54 – Age 66 (9) H&Y – not reported	55–85% of estimated HRmax	116 (20) bpm Around 75% HRmax	24 weeks of 30 min 2 × per week	60 min
Dag, Cimen [47]	N 13 – Age 58.2 (7.3) H&Y – I-II	MIIT at 50–70% VO2peak	Not reported	8 weeks of 4 × of 10 min on × 4 min off. 3 × per week – Total 40 min per session	120 min ‡

Week training volume – To calculate the week training volume, the maximal time exercising was considered. For example: If the duration ranges from 40 to 45 min, the 45 min was used to calculate week training volume. Same for frequency of training. For example, 2–3 sessions per week – the value of 3 was used

H&Y Hoehn and Yahr scale, *VO2peak* peak oxygen consumption, *HRmax* maximum heart rate, *HRR* heart rate reserve, *WRpeak* peak workload, *HIIT* high-intensity-interval training, *MIIT* Moderate interval training, *CPET* Cardiopulmonary exercise test

†Authors from this study do not clarify the time spent during the warm-up and/or cool-down. Then, the time in the table represents the time of the session and not the time exercising. ‡The 'work phase' of interval protocols was used to calculate week training volume as the 'recovery-phase' was passive

weeks exercising 3 × per week using an arm crank ergometer [47]. The 60-min MIIT protocol consisted of 4 × of 10 min of arm cycling at workload relative to 50–70% VO2peak interspersed by 4 min of recovery (total volume of 120 min). However, the study did not include a control group and the increase in VO2peak may reflect a learning effect [50].

HIIT requires lower training volumes compared with continuous protocols for comparable gains in aerobic capacity [51]. To date, the optimal training volume and the ideal time

frames for the work and recovery phases for HIIT protocols have not yet been defined for PD. Recent evidence from general and selected clinical populations suggests that work phases should be 2 to 4 min and a total time in high-intensity zone should be at least 15 min per session in order to maximize gains in aerobic capacity, but even shorter durations have been found to enhance fitness levels [26, 35, 52, 53]. HIIT protocols are not commonly used in PD, with only a few studies investigating their potential effect on aerobic capacity in this population [20, 40, 43].

Harvey et al., [43] examined the feasibility of a HIIT protocol using resistance machines in 16 PD participants whose VO2peak improved about 9% after 12 weeks of aerobic training. The protocol consisted of 3 weekly sessions of 4 × of 4 min 'work phase' (split in 45 s of exercising and 15 s to change from one machine to another) and 3.5 min of recovery. Over 80% of exercise repetitions were ≥ 85% HRmax, thus meeting the broad recommendation for high-intensity training. The total volume involved 36 min (12 min per session) of aerobic training (at high-intensity zone) per week, which is significantly lower compared to other protocols in PD. Demonceau et al., [20] reported a comparable level of improvement of 12% in VO2peak in 16 PD participants also after 12 weeks (2–3 sessions per week) of training using a mixed-protocol (continuous + HIIT). The first four weeks included continuous training at 50% of peak workload (WRpeak), obtained from CPET, for 30–45 min (2 × per week). From the fifth week, at least one session of interval training ('work phase' of 30 s to 3 min at 70–80% WRpeak and active recovery of 30–90 s at 50% WRpeak) was added until the end of the 12-week protocol. These studies suggest HIIT protocols have the potential to increase VO2peak in people with PD. However, a combination of continuous with HIIT protocols may be more beneficial.

On the whole, studies that incorporate HIIT protocols for people with PD appear to be well tolerated and feasible [20, 43] although this is not a universal finding. Uc et al., [40] withdrew participants from their HIIT protocol due to a higher risk of injury and lack of significant improvement in VO2peak compared to participants exercising continuously (2.0 ± 3.5 and 1.1 ± 2.7 mL/min/kg, respectively). Participants in the HIIT protocol were instructed to exercise at 80–90% HRmax interspersed by 60–70% HRmax, while those in the continuous group at 70–80% HRmax [40]. The authors from this study used age-predicted Eqs. (220-age) to calculate HRmax. Although both groups exercised at comparable mean HRmax (69.2% HRmax and 71.1% Hrmax, respectively), the mean HR attained at bouts of high intensity was not reported [40], which may have influenced the outcome.

Overall, research to date suggests that aerobic training using moderate to vigorous intensity protocols (per ACSM classification) produce gains in aerobic capacity in PD. Aerobic training protocols with a high volume of training in combination with vigorous to higher exercise intensities appear to elicit greater improvement in aerobic capacity compared with low-volume training at moderate intensities. However, the results need to be interpreted with some caution given the possible presence of CI, as shown in other clinical populations and our work, which may influence VO2peak [54, 55]. Also, the protocols we review here do not use threshold training zones (e.g., VT1 and VT2) to inform training regimes, which we consider to be more accurate and individualised. Moreover, gender, age, baseline fitness level, and genetic factors may also contribute to lack of improvement in VO2peak [4, 56].

Volume of training mediates improvement in motor function

Aerobic training protocols that adhere to principles of exercise intensity also report improvements in functional performance in PD (Table 3). Shulman et al., [22] reported an improvement of 12% in distance walked in the 6-min walking test (6MWT) for 22 PD participants after exercising on the treadmill at 40–50% HRR (moderate training zone—ACSM) for 150 min per week for 12 weeks. By contrast, participants exercising on the treadmill at 70–80% HRR (vigorous training zone—ACSM) for 90 min per week improved their 6MWT distance by only 6% [22]. Both groups showed a similar improvement in aerobic capacity (8% and 7%, respectively). These results suggest that training volume has a greater impact on function than intensity. Similarly, several studies report a significant improvement in VO2peak after training at moderate to vigorous intensities without concomitant improvements in 6MWT and timed up and go (TUG) scores [20, 21, 41]. This may reflect a lack of training specificity given that all studies used cycle ergometer, although it is not a consistent finding. Dag et al. [47] reported significant improvement in functional outcomes (6MWT and TUG) in PD after 8 weeks of aerobic training using an arm crank ergometer. The authors suggested that the interlimb connection, which is necessary during walking, was prompted during upper limbs exercises explaining significant gains in lower body functional performance [47].

Moderate and vigorous training improves motor symptoms

Training at moderate to vigorous intensity may also improve motor symptoms in mild to moderate PD. Schenkman et al. [39] reported a significantly *lower* change in the Unified Parkinson's Disease Rating Scale motor scores (UPDRS III) suggesting motor stability and therefore less disease progression, rather than worsening of symptoms after 6 months of 30 min on a treadmill (4 × per week) at

Table 3 Improvement in aerobic capacity, functional performance, and motor symptoms

	VO2peak (SD)		UPDRS III (SD)		6MWT (SD)		TUG (SD)	
References	Pre	Post	Pre	Post	Pre	Post	Pre (Sec)	Post (Sec)
Demonceau et al. [20]	23.4 (5.2)	26.2 (6.5)			553 (67)	584 (91)	1.8 (0.3) log-transformed	1.7 (0.2) log-transformed
Schenkman et al. [39]	23 (6) 24 (7)	+1.9 (2.9) +0.1 (4.4)	17 (7) 16 (7)	+0.3 (8.2) +1.8 (7.4)				
Uc et al. [40]	23.4 (5.6) 25.1 (8.2)	+1.1 (2.7) +2.0 (3.5)						
Sacheli et al. [41]	20.37 (5.05)	24.88 (6.03)	23 (10.42) 'off'	23.65 (11.49) 'off'			9.94 (1.52)	10.39 (3.03)
Kurtais et al. [42]	22.5 (4.7)	26.7 (5.0)						
Shulman et al. [22]	20.85 (SE 0.8) 23.58 (SE 1.2)	22.39 (SE 0.9) 25.11 (SE 1.4)			418.8 (SE 17.4) 440.9 (SE 29.0)	442.3 (SE 19.0) 490.0 (SE 34.0)		
Harvey et al. [43]	21.9 (3.9)	24.0 (5.3)						
Van der Kolk et al. [21]	26.6 (SE 1.1)	28.1 (SE 1.2)	19.4 (SE 1.8)	21.2 (SE 2.0)	499.4 (SE 18.2)	510.6 (SE 17.7)	8.3 (SE 0.5)	8.2(SE 0.5)
Penko et al. [44]	21.4 (3.9) 23.0 (7.6)	22.4 (4.9) 23.5 (6.9)						
Mavrommati et al. [45]	1.71 (0.11)	1.66 (0.09)						
Collett et al. [46]	1.65 (0.64)	1.63 (0.05)	16.7 (10.1)	14.1 (1.0)			9.4 (2)	9.9 (0.3)
Dag, Cimen [47]	18.33 (3.04)	23.92 (2.23)	26 (10.66)	22.53 (9.78)	476.76 (57.06)	530.07 (58.07)	9.94 (2.05)	8.20 (1.12)

VO2peak peak oxygen consumption, *UPDRS III* Unified Parkinson's Disease Rating Motor Scale, *6MWT* 6-min walking test, *TUG* timed up and go, *SD* standard deviation, *SE* standard error, *HIIT* HIGH-intensity interval training, *MIIT* moderate-intensity interval training

a higher intensity (mean 80.2% HRmax), compared with participants who trained at lower intensities (mean 65.9% HRmax). van der Kolk et al. [21] reported comparable findings on UPDRS III scores in favour of aerobic continuous training in participants who trained for 24 weeks at an average of 76.4% HRmax on a stationary bike. Dag et al. [47] also reported significant improvement in the UPDRS III (on-state) after 8 weeks of moderate interval intensity training. By contrast, Sacheli et al., [41] reported no change in UPDRS III (off-state) scores or cognitive test scores in 20 PD participants after 12 weeks exercising at moderate to vigorous intensity (60–80% VO2peak). The authors interpreted these findings as due possibly to measurement limitations or to a reverse causation effect (PD patients with better dopaminergic function are more likely to exercise). Despite this result, a tentative conclusion overall is that training at moderate to vigorous intensity rather than high intensity is sufficient to effect an improvement in motor symptoms and to stabilise symptoms over 6 months [21, 39, 47].

Is aerobic training neuroprotective?

Two recent studies using neuroimaging techniques and transcranial magnetic stimulation, revealed cortical and subcortical change in response to aerobic exercise, providing emergent evidence for exercise-induced neuroplasticity in PD [8, 41]. In a sub-group of participants from van der Kolk's study ($n = 57$), Johansson et al. [8] reported an increase in functional connectivity of cortical and subcortical structures, whilst Sacheli et al. [41] reported an increase in ventral striatum activity in 35 participants and enhanced dopamine release in the caudate nucleus in 25 participants. In line with the studies discussed above, participants in both of these sub-groups also exercised at moderate to vigorous intensity. Recent reviews provide more detail on this topic [57] as well as ongoing studies such as SPARX3 [9] aim to examine the mechanisms underpinning symptom stability following particularly high-intensity aerobic training.

Aerobic training protocols: current recommendations

Table 4 summarises the current guidelines for aerobic training in PD which overall recommend continuous training protocols at (predominantly) vigorous intensity. The ACSM guideline includes a progressive increase in exercise intensity based on the level of fitness and disease severity. The suggestion includes 30 min of continuous or accumulated aerobic exercise at intensities varying from 60 to 65% (more advanced PD) to 80–85% HRmax (mild to moderate PD) with the aim of improving aerobic capacity and modifying disease progression. [4]. In addition to a progressive increase in exercise intensity based on the level of fitness, Kim et al. [58] suggest a progressive rise in training volume from 20 to 60 min, while Martignon et al. [59] propose altering training volume and exercise intensity as the disease progresses. The recommendation from Albert et al., [10] does not highlight a progressive increase in training intensity and volume but recommend using RPE to monitor exercise intensity if autonomic dysfunction (CI) is presented. However, given its subjectivity, in such cases the RPE may be better suited as an adjunct to more accurate measures of aerobic intensity [60].

While HIIT is feasible and shows potential for improving aerobic capacity in individuals with PD [20, 43], it is not included in these recommendations. Training based on the threshold zones is also not recommended, possibly because of the need for expensive equipment (CPET) and because viable alternative such as %HRmax or %HRR exists. The guidelines for PD do not present specific exercise intensity parameters or volume of training for enhancing aerobic capacity, functional performance, or symptoms related to PD. Additionally, there is no indication of the most suitable exercise modality for achieving these outcomes. In general, the optimal frequency, intensity, time, type, volume, and progression, the so-called FITT-VP principle of training [61], are unclear for people with PD.

Autonomic disturbance affects response to exercise

The method for calculating training intensity may also influence exercise safety and training outcomes for people with PD, particularly for those with autonomic disturbance. A common feature of autonomic dysfunction is chronotropic incompetence (CI), defined as the inability to raise HR (usually up to a threshold of 85% age-predicted HRmax) in proportion to the increased exercise demand despite physiological and clinical measures indicating that maximal effort has occurred [62, 63]. Other features of the autonomic nervous system, such as heart contractility and fatigue, impacting aerobic capacity and exercise programming in PD, is beyond the focus of this narrative review [64, 65].

The estimated prevalence of CI in PD is 40–50% and its effect on response to exercise is gaining interest [44, 66]. Penko et al., [44] reported that 60/100 (40%) of participants with CI were unable to achieve 85% of their age-predicted HRmax during CPET, while Kanegusuku et al., [67] reported that only 35.4% and 8.3% achieved 90% and 100%, respectively, of their age-predicted HRmax. In PD, CI is most likely due to dysfunction of the sympathetic innervation [66, 68], and is difficult to detect at rest and during low-intensity exercise [67]. Traditional equations using age-predicted HRmax (e.g., 220-age) can be inaccurate at determining training intensity in PD with CI, even when using the HRR equation because resting HR measures are often comparable to normal values [67–70].

Unpublished CPET data from our laboratory reveal that physically active individuals with PD with CI had a mean HRmax that was approximately 30 beats per minute below their age-predicted HRmax and although they exercised at high intensity (based on CPET threshold zones) it was at a much lower absolute HR compared to participants without CI (Fig. 1). A similar outcome is seen if general training guidelines are used for aerobic exercise prescription in this population (Fig. 2). These results highlight the inaccuracy of age-predicted equations, underestimating training zone

Table 4 Aerobic protocols guidelines for people with PD

References	Exercise intensity	Duration	Frequency
Martignon et al. [59]	Early stage 60–89%HRR	45 min	3 × per week
	Moderate stage 40–59%HRR	30–40 min	Daily
	Advance stage 30–59%HRR	20 min or 2 × of 10 min	Daily
American College of Sports and Medicine [4]	60–65%HRmax 80–85%HRmax	30 min	3–4 × per week
Albert et al., [10]	60–80%HRR or 70–85%HRmax or 14 -17 RPE	30–40 min	3 × per week
Kim el al., [58]	60–80% HRmax or 40–60% HRR	Gradually increase from 20 to 60 min	3–5 × week

HRR heart rate reserve, *HRmax* maximum heart rate, *RPE* rate of perceived exertion

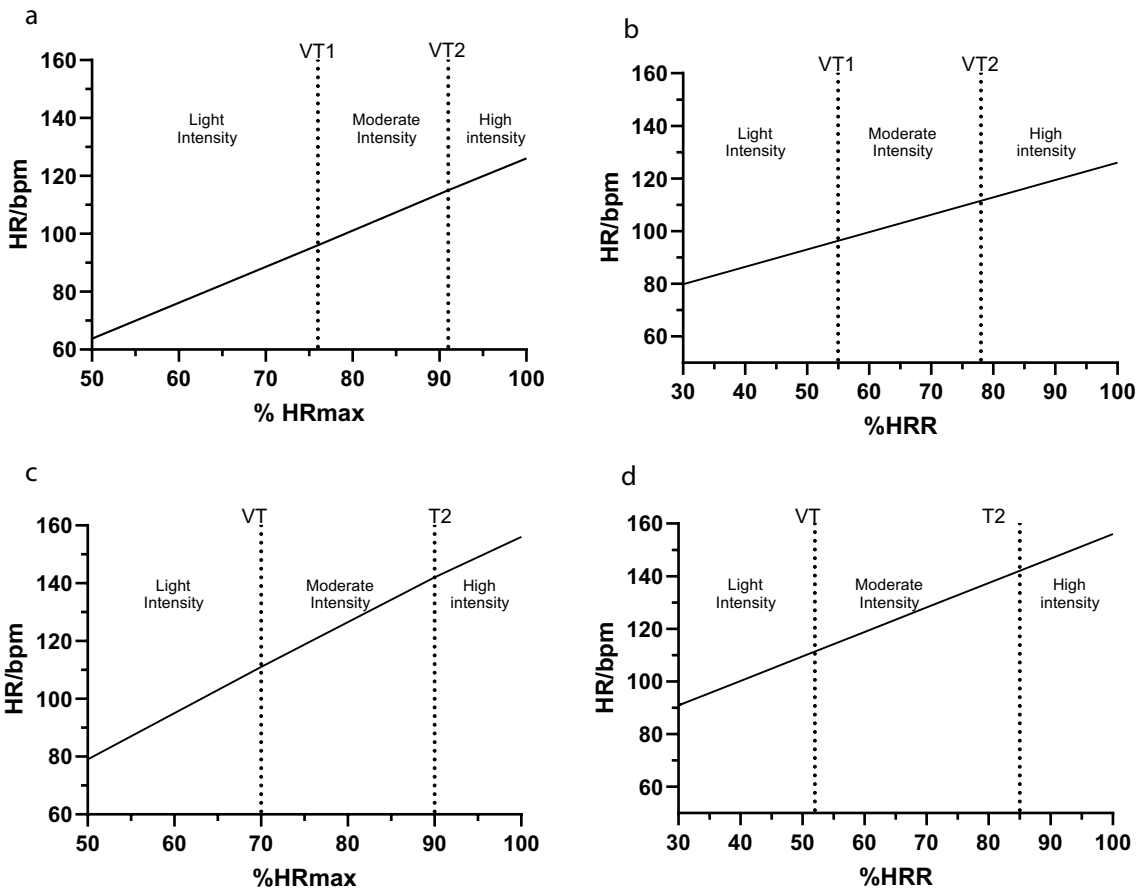

Fig. 1 Mean HR versus percentage of HRmax and HRR attained from 13 PD subjects with (**A** and **B**) and 15 without CI (**C** and **D**) during an incremental CPET to exhaustion. The mean VT1 and VT2 for each group are used to identify the thresholds for each training zone (light, moderate, and high intensity). The mean HRmax in people with PD with CI is 126 bpm (beats per minute) and without CI is 156 bpm. The mean resting HR in people with PD with CI is 60 bpm and without CI is 63 bpm. HRR was calculated using the following equation: ((HRmax)—resting HR) + resting HR). HRmax represents the maximum HR attained during CPET. Figure based on unpublished data from our laboratory

for people with PD with CI, and the needs of using individualized measures for determining exercise intensity if data from CPET is available.

PD medication and aerobic training

As the mainstay of symptom management in PD, dopaminergic replacement does not appear to influence HR responses or measurement of VO2peak [68]. Testing and measurement procedures are commonly carried out in the 'on' state (usually 1 h after the medication), but advice for training sessions is less evident. There is a general rule that exercising 'on' is optimal, with some people administering an extra dose to boost the 'on' state during exercise [11]. However, it is unclear whether the timing of medication has a beneficial or deleterious effect on gains in aerobic capacity.

Conclusion

Whilst there is a positive effect of intensity on aerobic performance (VO2peak) in PD, its influence on motor symptoms and function is less clear. The emphasis on intensity during training has potentially devalued the role of volume and exercise modality in influencing these outcomes. Comprehensive reporting of training protocols is required to optimise outcome, whilst acknowledging the limits of predicted equations to determine training zones and response to training. Lastly, further research is required to understand the marked effect of CI on aerobic performance and the need to identify this sub-group within a study population.

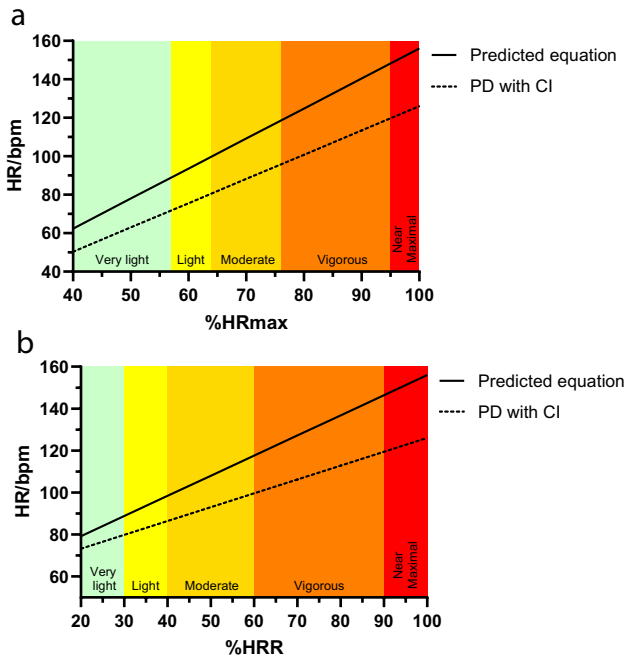

Fig. 2 Comparison of training zones using the %HRmax (**A**) and %HRR (**B**) according to the ACSM classification of exercise intensity in people with PD with CI based on actual maximum heart rate (HRmax) and predicted equations. The dotted lines represent percentage of actual HRmax, and HRR based on CPET results obtained from 13 PD participants with CI. Predicted HRmax was calculated using the Eq. 220-age. Predicted HRR was calculated using the equation ((220-age)—resting HR) + resting HR). The mean age of these individuals is 63 years old, and the resting HR is 60 bpm. Figure based on unpublished data from our laboratory

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Declarations

Conflict of interests The authors declare no competing interests.

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