Does Resistance Training Reduce Falls and Improve Quality of Life in People with Parkinson's Disease using Strength Training Exercise Programmes?

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Background: Parkinson's Disease (PD) is the second most common neurodegenerative disorder behind Alzheimer's, affecting around 1% of the population over 50 years old. PD is associated with inhibited motor functions including tremors, muscle rigidity, impaired posture, bradykinesia (slowed movement) and loss of balance. Physical activity is thought to be one of the most important non-pharmacological strategies to target and improve the management of motor symptoms of PD.

Objective: To identify the effect of Strength Training (ST) on Falls and Quality of Life (QOL) on people suffering with PD.

Method: A systematic search of AMED, Cinahl, Cinhal Plus, CSP Online Library Catalogue, Medline and SportDiscus was conducted; articles were searched until November 2018.

Results: Eleven studies were included in this review, with a total of 549 participants of which 539 had a confirmed diagnosis of PD, 10 did not. All eleven included studies were randomised control trials. The training volume including repetitions, sets, frequency and intensity varied between all studies. Interventions showed positive trends in reducing the proportion of fallers and improving QOL Scores.

Conclusion: There is some evidence to show that ST is effective at improving strength in People with Parkinson's Disease (PwPD) and has some passover effects in reducing falls and improving QOL. Future research is required to determine if optimum guideline training volumes for PwPD better support the secondary effects on falls and QOL.

Keywords: Parkinson's Disease; Strength Training; Quality of Life; Falls

1.0 Introduction

Parkinson's Disease (PD) is an age related neurodegenerative disorder associated with inhibited motor functions including tremors, muscle rigidity, impaired posture, bradykinesia (slowed movement) and loss of balance (1). PD can also cause a range of other physical, cognitive or psychiatric symptoms for example depression, anxiety, autonomic- sleep and sensory disturbances (2). PD is the second most common neurodegenerative disease behind Alzheimer's, affecting around 1% of the population over 50 years old (3). Prevalence of PD seems higher in Europe, North America and South America compared to African, Asian and Arabic Countries (4). It is estimated that around 1 in 500 people are affected by PD, meaning there is an estimated 127,000 people in the United Kingdom (UK) living with the condition (5) with more men diagnosed than women (4,5).

PD is characterized by the reduction and loss of dopaminergic neurons of the substantia nigra pars compacta within the basal ganglia, the main region affected by this disease. Over time, the loss of these neurons results in the known symptoms (6). These often lead to a decrease in physical activity and movement in people suffering with PD, which in turn further inhibits their strength and everyday physical functioning (7). Subsequently, people affected by PD are nine times more likely to experience a fall compared to a generic "healthy" older adult of the same age (8). The current and most commonly used pharmacological drug based approach to treat PD include levodopa, dopamine agonists, catechol-O-methyl transferase (COMT) inhibitors, and non-dopaminergic agents (4,5,9–11). Although these drugs may help with the associated motor symptoms, the drugs do not stop the progression of the PD, they only aim to slow down the process (12,13).

Physical activity is thought to be one of the most important non-pharmacological strategies to target and improve the management of the motor symptoms of PD while also delaying the disease progression (14,15). Currently, there are very few evidence-based guidelines for strength/resistance training (ST)/(RT) for people with PD and insufficient well controlled high study quality trials have been performed (16). However, physiotherapy and physical activity is recommended, as one of the non-pharmacological management methods to improve the quality of life for the people with PD, as located within the National Institute for Health and Care Excellence (NICE) guidelines section 1.7.2- 1.7.4 (11). Exercise has been shown to be beneficial for people with PD (17). RT has been shown to improve strength, various measures of physical functions and maintain walking ability in those with mild to moderate PD (18,19). It has also been suggested that RT may have a protective effect and slow down disease progression however this is still unclear (20).

With current trends and evidence suggesting that exercise is beneficial for PD suffers, a newly developed ten-week intensive exercise-based commercial product programme has been developed in Australia, the product/service is called 'PD warrior'(21).

PD Warrior is an intensive exercise-based program designed to drive neuroplastic change in people with Parkinson's. It is in stark contrast to the compensatory movement and cueing strategies employed in current clinical practice. Our approach is designed to help people live with Parkinson's better by improving the way they move – either by increasing their effort, amplitude, dual tasking or a combination of all three… we expect that people with idiopathic Parkinson's, doing PD Warrior as it is designed, should be able to improve on their clinical outcome measures, capacity to exercise long-term and overall confidence levels (21)

PD warrior claims to drive neuroplastic changes within the brain however current literature cannot agree with the current statement (22,23). Sources state that "exercise may induce central neuroplasticity changes" (22) and that "The implications for our understanding of the impact of exercise in PD are broad"(23). However, it is agreed that benefits are noted from exercise for people living with PD, these benefits include improvement in muscle strength, increased aerobic capacity and reduction in gait and balance dysfunction (19,22,23). Although physical exercise is of overall benefit for the health and functional capabilities of someone affected by PD, the best exercise regimen is yet be determined.

Nevertheless, physiotherapy and physical activity cannot reverse the symptoms of PD; it can only aim to aid in the improvement of the quality of life and independent functional ability of people with Parkinson's Disease (PwPD). Moving forward, the purpose of this literature review is to explore the impact of training on motor symptoms for those that have PD. The primary objective of the literature review is to identify the effect of ST/RT on people with PD.

2.0 Methods

2.1 Data Sources and Search Strategy

The following electronic databases were searched for English language literature: AMED (Allied and Complementary Medicine Database), CINAHL (Cumulative Index to Nursing and Allied Health Literature), CINAHL Plus with Full Text (Cumulative Index to Nursing and Allied Health Literature), CSP Online Library Catalogue, Medline and SportDiscus. A copy of the full search strategy and key words/terms for each database can be found in Appendix 1. Alongside the computerised search a manual search of reference lists of selected papers and reviews on the specific topics were performed to identify additional relevant articles. Grey literature was identified through a search on Google and Google Scholar using the aforementioned keywords within Appendix 1. The electronic databases were searched until November 1st, 2018. Reference lists of all the applicable articles were also examined for identification of further eligible studies.

2.2 Inclusion and Exclusion Criteria

RT was defined as a form of ST that is designed to improve components of muscular fitness including strength, power and endurance. ST/RT is defined as an intervention in which participants exercise a muscle or group of muscles against an external resistance. A range of equipment can be used to apply an external resistance against the body's muscles this includes bodyweight, free weights, machines with additional weights, elastic bands or water pressure (24–26). In deeper analysis, articles in which the effect of ST/RT in subjects with PD were assessed with the following criteria based upon the following PICO (Patient, Intervention, Comparison, Outcome) principles.
Inclusion Criteria:

- Subjects with PD
- Adults aged 19 years and above
- Male and Female subjects
- Study design comparing the effects of ST/RT versus different exercise with the effects on PD symptoms
- Outcomes: muscle strength, physical performance, quality of life or falls

- Only fully peer-reviewed articles with full text available in English

Exclusion Criteria:

- Studies using intervention therapies in addition to ST/RT
- Studies where ST/RT was a secondary finding compared to the primary intervention e.g. balance
- Systematic Reviews from the bibliographic search
- Articles that are not written fully peer-reviewed with full text available in English
- Studies where subjects with PD were not included
- Studies assessing patients aged 19 and below

One author (JCC) independently screened the articles by title and abstract against the selection criteria. Articles that were unclear from their title or abstract were reviewed against the selection criteria through the full text. Any discrepancies were resolved through discussion with the fellow author (JJ). If the article passed the first step, then the second step was to screen the full-text article.

2.3 Data Extraction

Data were extracted by one author using a customised form (JCC). This was used to extract relevant data on title and authors, research question & study type, methodological design, study sample, summary of findings, study limitations & Critical Appraisal Skills Programme (CASP) (27) score and the clinical intervention/relevance. In cases where supplementary methodological information could not be sourced then a not reported statement was assigned. There was no blinding to study author, institution or journal at this stage.

2.4 Assessment of Risk of Bias

All articles that satisfied the defined inclusion criteria as seen previously in 2.2 were independently rated for quality. The methodological quality of the selected articles were assessed using the Critical Appraisal Skills Programme Tool (CASP) (27). The CASP tool within this review was used to quantify the level of evidence being synthesised and highlight any means of bias that may be evident. For the purpose of this review, studies were included if they achieved a score of 5>. High quality evidence will be scored from 8-11, medium quality evidence 5-7, and low-quality evidence 4< excluded from the review. Both authors (JCC) and (JJ) assessed the scores independently. The authors were not blinded to the score or quality of assessment. Any discrepancies were resolved through discussion with one another.

3.0 Results

3.1 Overview of the inclusion process and methodological quality assessment

The review process is presented within Figure 1; One thousand three hundred and thirty articles were identified in the initial search strategy. One thousand one hundred and ninety-one articles were excluded from the study as they either contained duplicate articles, review articles, conference proceedings, book chapters or articles written in languages other than English.

Of the remaining one hundred and thirty-nine studies, one hundred and twenty-eight did not meet the inclusion criteria as previously reported within section 2.2. A total of eleven articles were included in this review as shown within the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram (Figure 1) (28). The CASP scale score of the eleven articles is reported in Table 1 below. All Studies included had both authors (JCC) and (JJ) approved CASP Scores of five or higher indicating a low risk of bias and were therefore included within the review.

[Table 1 near here]

3.2 Qualitative Analysis

3.2.1 Study Cohort

The eleven studies comprised of a total 549 participants, 539 of these had PD, 10 did not have diagnosed PD. The study including participants without PD (37) met all the selection criteria for this review; PwPD were in a separate group to those without and their data were analysed independently and compared to the non-PD group.

All studies reported the age of their participants; overall the range of the participants varied between 40-90 years old. Age was described as set range or an average within the studies. PD severity was described using the Hoehn and Yahr scale (H&Y) (40) in all studies. All but two studies used disease severity 1-3 H&Y scale participants within the study. One study allowed anyone with a score of less than 5 to participate within the study (31). One other study used an average of people with moderate disease severity ranging from 2.2 +/- 0.41 to 2.3 +/- 0.53 on the H&Y scale (39).

3.2.2 Training Volume

All studies utilised either strength or resistance training. The implementation of the ST/RT varied widely across the studies. The protocol of the ST/RT training was reported within all 11 of the studies (29–39) as can be seen in Appendix 1.

The majority of studies targeted the lower limbs in the ST/RT exercise programmes with few studies including supplementary upper body exercises. The lower limb exercises predominantly focused on knee and hip extensors, knee flexors and ankle plantar flexors, these are all used in standing and balance of the human body. Exercise frequency was either two (29,30,32,34) or three days per week (30,33,35,37,38). One study's frequency was once per week (31) with another reporting, Eighteen sessions over ten weeks (36).

Volume of training sets varied between 2-3, two studies were time dependent in their volume(37,38). Intensity levels were specified in all eleven studies; eight studies intensity was measured as a % of the participants 1 Repetition Max (RM). The three remaining studies described intensity in a more indirect method, including <5 on the Modified Perceived Exertion Scale (31), Intensity as tolerated for 10 repetitions (33) or maximal contraction for 5s (35).

[Table 2 near here]

3.2.3 Falls

Only two of the eleven selected studies assessed falls rate during their trials (31, 34). Both studies reported fewer falls rate within the ST/RT exercise groups compared to the control groups. One study (31) reported 1547 falls over the 12-month period; 193 for the progressive resistance strength training group (PRST), 441 for the movement strategy group (MST) and 913 for the control group.

The strength training group (31) had 85% fewer falls than control (incidence rate ratio [IRR] = 0.151, 95% CI 0.071-0.322, P < .001). The movement strategy training group had 61.5% fewer falls than control (IRR = 0.385, 95% CI 0.184-0.808, P = .012)(41). As this study specifically measured falls rate there was supplementary data on falls injuries associated with this study. A total of 44 injurious falls, defined as attending a health service as a result of the fall, were reported by 33 participants: 11 participants in the PRST group, 12 in the MST group, and 10 in the control group. Fractures occurred as a result of a fall in 8 participants; 3 participants in each of the PRST and MST groups and 2 in the Life skills (LS) control group.

Falls resulted in 16 participants (6 from the PRST group and 5 each from the MST and control groups) being taken to hospital, with 6 being admitted for at least one night. Local doctors were consulted by 25 participants on 28 occasions following a fall (31). One study (34) reported a total of 172 falls, 62 falls were reported by participants in the power training group and 110 falls by participants in the control group. There was a 16% reduction in fall rate in the power training group compared with the control group, this however was not a significant difference (incidence rate ratio 0.84, p = 0.76). Seven of the 19 (37%) participants in the power training group fell compared with 12 of the 19 (63%) participants in the control group. One participant in each group had incomplete falls data reported (34).

3.2.4 Quality of Life

Five of the eleven selected studies assessed the quality of life (QOL), administered through two different questionnaires: PDQ-39 and the EuroQol-5D VAS. The UDPRS-II has not been reviewed as it was used as a measure of mobility and functioning compared to QOL assessment within the studies. All five studies included the PDQ-39 within their QOL assessment (30–32,35,39). One study also included the EuroQol-5D VAS (31). One study showed no trend in the QOL assessment scores (30). One study showed a statistical significant difference in the QOL score ($P < 0.05$) (32) with another showing a significant between group difference score ($P < 0.02$), this scoring was significant at six months however there was no difference after twenty four months (39). The study using both the PDQ-39 and the EuroQol-5D VAS found no group difference from baseline to 12 months, with the exception of the PDQ-39 score in the progressive RT compared to the Life Skills (LS) control group ($P <0.05$)(31).

4.0 Discussion

4.1 Study Cohort

The eleven studies provided a sample cohort mainly representative of the early stage PD suffers. As described only one study included people with H&Y <3 which is not representative of the whole PD population, therefore showing exclusion and possible bias within the data set. Generally, the data matches the known age and onset of PD with the disease mainly affecting middle aged to elderly adults (3,42,43). It is not currently known if ST/RT is beneficial for more advanced stages of PD H&Y <3 and if the exercise would be suitable and tolerable for people in the later stage of the disease who not only have worsening motor function but also cognitive symptoms, this would require further prospective studies to deem whether a focus on exercise is appropriate.

4.2 Training Volume

In this review, variation was shown across all studies for training volume including; repetitions, sets, frequency and intensity. This makes it difficult to identify the most appropriate characteristics of training volume that make an effective ST/RT intervention that could be clinically reasoned against guidelines for prescription to people with PD (44,45).

This evidence highlights the need for more research into training volume to be undertaken. From the evidence it suggests that ST/RT with other forms of exercise and education may be the most effective to increase strength and provide a holistic approach to wellbeing in people with PD (31).

Guidelines for ST/RT in PD have been advised previously (16) which generally supports the literature reviewed. As highlighted the variance in training between studies is evident, the current 2018 American College Sports Medicine (ACSM) guidelines for exercise testing and prescription in healthy adults and people with PD do not differ from one another with the same recommended; repetitions 8-12, sets >1 , frequency 2-3 times per week and intensity 40-50% of 1RM for novice/beginners and 60-70% of 1RM for more advanced users (45). The reporting of all training characteristics is shown (table 2), however there are distinct differences to the current recommended guidelines. As the volume of the training varied between the studies it is therefore reasonable to question if "strength" was being trained according to the ACSM exercise guidelines. This leads to doubt that the studies were truly 'strengthening' within their prescribed exercise programmes and then measuring strength as an outcome measure.

The findings also indicate that eccentric RT resulted in greater strength gains compared to other forms of ST/RT in people with PD as evidenced with statistically significant improvements in these training groups (35,38). These findings should be taken with caution as both corresponding studies did not include a true non-exercise control group, alongside (35) only completing 3 maximal quadricep eccentric contraction repetitions (35), or exercised for time as opposed to sets (38), therefore neither study met the recommended ACSM guidelines and the ACSM recommendations for exercise management for persons with chronic disease and disabilities (46), both studies also scored low within the quality of evidence CASP scoring system (Table 1).

Future recommendations would include completing an eccentric based programme following the recommended guidelines with a true non-exercise control group over a set period. It is important to note that the reporting of training volume characteristics within the included studies was consistent even if varied. Overall, the studies suggest an overall improvement to muscle strength following the set ST/RT exercise programmes; the exercise programmes however are too inconsistent to draw a definitive conclusion on the best evidenced set training volume characteristics. Nevertheless, results show that following ST/RT exercise programmes people with PD consistently improve (30,32,34,35,37,39) their muscle strength with prescribed ST/RT exercises.

4.3 Falls

There was a distinct lack of falls reported within the eleven studies. However, the data collected do show a positive trend that ST/RT may be beneficial for reducing the proportion of fallers compared to non-exercise controls groups. Morris *et al* (31) found a significant difference between the ST group and the non-exercise control group.

The strength training group had 85% fewer falls than control. However, the study has limitations due to the control group being aware of their group assignment, which could have been the cause of the higher rate of drop out within the group therefore could have been a potential source of bias within the study which could have resulted in the significant findings between the ST and LS control group.

The non-statistically significant findings from Paul *et al* (34) may be caused due to the small sample size within the data set. Usually small sample sizes do not yield reliable or precise estimates which therefore is usually a common indication to not make a strong conclusion from the trial's intervention and findings (47). However, when working with people with PD there are generally only going to be small sample sizes due to the uncommonness of the disease and the clinical trials having to conform to ethical principles.

This therefore could show reasoning that the results need to be interpreted carefully and when multiple studies suggest the same view on a specific finding then this may be indicative of the benefits that could be found from the corresponding treatment. Subsequently, people suffering with PD are known to be nine times more likely to experience a fall compared to a generic "healthy" older adult of the same age (8). Therefore, it would seem apparent that falls would be a key outcome measure within any treatment effect from a study focusing on PD, due to the known risk of falling possibly resulting in fractures and inpatient hospitalisation costing the National Health Service (NHS) an estimated £4.6 million per day in over 65's alone (48).

4.4 Quality of Life

In this review, variation is shown between the results however there is a common trend that generally ST/RT improved the QOL questionnaire scores. The data trends suggest that further QOL testing would be beneficial to definitively reason if ST/RT has a positive effect on QOL for people with PD. From the evidence reviewed Morris, M.E *et al.* (31) study's findings from the EuroQol-5D VAS questionnaire must be questioned.

The EuroQol-5D VAS is not a PD specific questionnaire, and although research (49) has found it has good feasibility and validity in PD and correlates moderately to disease severity H & Y scale it has not been assessed for sensitivity to change. The EuroQol-5D VAS was also found to have correlated well with the PDQ-39 however the sensitivity to change commonly seen in clinical trials to test effectiveness has not yet been assessed. This means that the EuroQol-5D VAS still needs conformation and comparison to new sets of people with PD with the sensitivity assessed before it can be reliably used as a PD QOL questionnaire.

Four studies all showed an improvement in PDQ-39 QOL scores (32,38,39,41) with two of these providing statistically significant improvements ($P < 0.05$) (32), ($P < 0.02$) (39). The literature suggests that PD sufferers can experience QOL improvements in response to ST/RT exercise programmes. The duration of the effects can be seen over a minimum of six months of ST/RT (39), however as this is a known progressive disease the QOL may have decreased over a longer period of time therefore providing reason why no difference was found post twenty four month assessment. The literature also suggests that psyco-social aspects of QOL including; emotional wellbeing, communication and cognitive impairment, can be coped with better through group ST/RT exercise (30). ADL's, mobility, social support and overall PDQ-39 sum values have also been shown to have improved post training (32).

The validity of the PDQ-39 has been widely used and accepted across a large sum of people with PD around the world (50–53). The PDQ-39 has been shown to demonstrate internal consistency (0.72-0.95), test-retest reliability (0.67-0.87) and reproducibility (0.68-0.94) (52,54). However, further application of the PDQ-39 continuing to be used within ongoing clinical trials would further contribute to the validation and interpretation of the questionnaire as an appropriate QOL outcome measure (54). In most situations the PDQ-39 is the most appropriate quality of life assessment to be used within PD due to the validation and reliability of the disease-specific QOL measure.

4.5 Conclusion

Overall, there is some evidence to suggest that ST exercise programmes are effective at improving strength in people affected by PD. It is also suggested that ST has some carry over effects on the reduction of falls and QOL within PD.

This conclusion is based upon limited clinical trials achieving a score <5 on the CASP scoring system ranking from medium to high quality of evidence, involving relatively small sample sizes with a variance of reported training volumes including minimal studies measuring the reported secondary effects in the reviewed studies and are not definitive.

However, further well reported clinical RCT's are needed and would be beneficial to support further use of ST for people suffering from PD to assess if the guideline training volumes better support the secondary effects of falls and QOL with these people compared to a true non-exercise PD group.

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Appendix

Appendix 1. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Carvalho, A *et al.* (29)	Training volume composed of 2 sets of 8-12 repetitions at 70-80% of 1RM with a rest interval of 1 minute 30 seconds. Exercises completed were leg curls, leg press, chest press and low row.	Chair Stand Test, Arm Curl Test, 2 Minute Step Test, Chair Sit and Reach Test, Back Scratch Test, 8-Foot Up and Go Test, 10 Metre Walk Test, Berg Balance Scale.	X	X	X

(Continued)

Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Demonceau, M *et al.* (30)	Training volume composed of week 1-5, 10-15 repetitions at 50-60% of 1RM. Week 6-12, 5-8 repetitions at 80-90% 1RM. Exercises completed were leg extension, leg curl, latissimus pull down,	Concentric Knee Extension Strength, Incremental Exercise Test on Cycle Ergometer Until Exhaustion, Gait Analysis, Timed Up and Go Test, 6 Minute Walk Distance,	X	✓	X

	calf and leg press, overhead pull up and arm flexion.	Physical Activity Status Scale.			

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Morris, M.E *et al.* (31)	8-week intervention followed by a 12-month ongoing falls assessment. The participant 1 clinic session per week comprising of 15	Falls Rate, Disability UPDRS and Activities of Daily Living, 6 Minute Walk Test, Times Up and Go Test, PD Quality of Life,	✓	✓	✓

	repetitions to a maximum of 3 sets. Resistance provided by weighted vest, thera band or body weight.	Health Related Quality of Life, Number of Injurious Falls and Time to First Fall.			

(Continued)

Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Ni, M *et al.* (32)	12-week power training, patients completed 2x sessions per week, 3 sets circuits of 10-12 repetitions on each	Limb Bradykinesia (upper and lower limb), 1RM and Peak Power on: Bicep Curl, Chest Press,	X	✓	X

	pneumatic machine at 30-90% 1RM. Exercises completed were bicep curl, triceps push down, chest press, seated row, latissimus pull-down,	Leg press, Hip Abduction and Seated Calf Raise.			

(Continued)

Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Ni, M *et al.* (32) continued.	Shoulder press, leg press, leg curl, hip abduction, hip				

	adduction, seated calf raises.	

(Continued)

Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Shulman, L.M *et al.* (33)	Training volume composed of 2 sets of 10 repetitions on each leg on 3 resistance machines: leg press, leg extension and leg curl, weight was increased as tolerated. Training was completed 3 times a week for 3 months.	Gait Speed (6 Minute walk test), Peak Oxygen Consumption Per Unit Time (VO2), Muscle Strength (1RM)	X	X	X

(Continued)

Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Paul, S.S *et al.* (34)	Participants trained in pairs for 45 minutes twice a week for 12 weeks. Each participant performed 3 sets of eight repetitions as fast as possible for each muscle group on each leg. The first set was completed at 40% of 1RM, 2nd 50%, 3rd at 60%.	Peak Muscle Power- leg extension, knee flexors, hip flexors, hip abduction, 1RM Testing, 10m Fast Walking, Timed Up and Go Test, Choice Stepping Reaction Time,	✓	X	X

(Continued)

Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Paul, S.S *et al.* (34) continued.	This was increased by 5% when 10 repetitions could be performed.	Single Leg Stand, Freezing of Gait Questionnaire.			

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Dibble, L.E *et al.* (35)	Training volume composed of walking on a treadmill, cycle ergometer and performing high-force eccentric training on an eccentric ergometer, progression of work rate	Peak Muscle Force, Severity of Motor Defecits, Disease Specific Quality of Life (PDQ-39), 10 Metre Walk Test, Timed Up and Go Test.	X	✓	X

	was determined by RPE using a target workload.				

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Dibble, L.E *et al.* (35) continued.	This was all completed within a 45-60-minute session 3 days a week for 12 weeks.				

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Hass, C.J et *al.* (36)	The resistance training group completed an orientation session, 1RM	Biomechanical Gait Analysis and Dependent Variables,	X	X	X

	testing and a 10-week training programme. The training consisted of a 5-minute warm up, participants performed two sets of 12-20 repetitions to volitional fatigue.	Displacement of centre of Pressure, Stride Length and Velocity.			

(Continued)

Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D

Hass, C.J et *al.* (36) continued.	Exercises completed were leg press, knee extension, knee flexion, abdominal curl, back extension and seated calf raise. Followed by a multidirectional ankle theraband protocol. Participants completed 18 sessions over 10 weeks.

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Peacock, C. A *et al.* (37)	The training consisted of an 8-week training program, consisting of 24 separate sessions. The resistance training utilised weight machines, closed kinetic chain activities and variable resistance training. The protocol prescribed multi-joint exercises ranging from 12-15 repetitions using	Cardiovascular performance- Heart Rate and Exercised Heart Rate, Muscular Strength-1RM Testing, Muscular Endurance- Curl Up Test, Flexibility- Sit and Reach Test	X	X	X

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Peacock, C. A *et al.* (37) continued.	55-67% of the participants 1RM.				

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Dibble, L.E *et al.* (38)	The strength training group performed their exercises over a 45-60-minute period, 3 days a week for 12 weeks. The eccentric strength training group used the eccentric	Muscle Volume (CM3), Average Torque, Six-minute Walk Test (M), Stair Descent (Sec), Stair Ascent (Sec)	X	X	X

	ergometer. Progression was based upon RPE.				

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Dibble, L.E *et al.* (38) continued.	They also completed upper body resistance exercises upright row and latissimus pull down.				

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Corcos, D.M *et al.* (39)	The resistance training consisted of 11 strengthening exercises	Quality of Life (PDQ-39), Muscle Strength, Movement Speed,	X	✓	X

	consisting of chest press, latissimus pull down, reverse fly, double leg press, bicep curl, shoulder press, biceps curl, shoulder press, triceps extension, back extension, knee extension, hip extensions and rotary calf.	Modified Physical Performance Test			

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Appendix 1 Continued. Strength/Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D

Corcos, D.M *et al.* (39) continued.	Resistance was set at 30-40% of 1RM for upper body exercises and 50-60% for lower body exercises, intensity increased by 5% or as allowed by the equipment. Participant's performed 3 sets of 8 repetitions for 8 weeks and then 2 sets of 12 repetitions for 8 weeks

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Appendix 1 Continued. Strength Resistance Training Protocol, Assessment Measures and Outcome Measures.

Study	Strength/Resistance Training Protocol	Assessment Measures	Outcome Measures		
			Falls	PDQ-39	Euro Quol 5D
Corcos, D.M *et al.* (39) continued.	Participants alternated between both programs for the duration of the study, they completed the exercises 2 times a week for 18 months. The resistance was set at where they left off for the respective programs.				

Abbreviations: RM, Repetition Max; PD, Parkinson's Disease; RPE, Rate of Perceived Exertion.

Table 1. Study design quality assessment based on CASP Score and author approved evidence quality

Study	Total CASP Score	Quality of Evidence Based Upon CASP Score
Carvalho, A *et al.* (29)	10/11	High
Demonceau, M *et al.* (30)	8/11	High
Morris, M.E *et al.* (31)	10/11	High
Ni, M *et al.* (32)	9/11	High
Shulman, L.M *et al.* (33)	10/11	High
Paul, S.S *et al.* (34)	8/11	High
Dibble, L.E *et al.* (35)	10/11	High
Hass, C.J *et al.* (36)	7/11	Medium
Peacock, C. A *et al.* (37)	9/11	High
Dibble, L.E *et al.* (38)	8/11	High
Corcos, D.M *et al.* (39)	10/11	High

Abbreviations: CASP, Critical Appraisal Skills Programme.

Table 2. Training Volume Characteristics (*N/R- Not Reported*)

Study	Repetitions	Sets (Volume)	Frequency (days per week)	Intensity
Carvalho, A *et al.* (29)	8-12	2	2	70-80% 1RM
Demonceau, M *et al.* (30)	10-15 then 5-8	2-3 patient dependent	2-3	50-60% 1RM then 80-90% 1RM
Morris, M.E *et al.* (31)	Maximum 15	Maximum 3	1	<5 on the Modified Perceived Exertion Scale
Ni, M *et al.* (32)	1-12	3	2	30-90% 1RM
Shulman, L.M *et al.* (33)	10	3	3	Intensity as tolerated for 10 reps
Paul, S.S *et al.* (34)	10	3	2	40% Set 1, 50% Set 2, 60% Set 3
Dibble, L.E *et al.* (35)	3	N/R	3	Max contraction for 5s

(Continued)

Table 2 Continued. Training Volume Characteristics (*N/R- Not Reported*)

Study	Repetitions	Sets (Volume)	Frequency (days per week)	Intensity
Hass, C.J et *al.*	12-20	2	18 sessions over 10 weeks	70% 1RM
Peacock, C. A *et al.* (37)	12-15	30 minutes	3	55-67% 1RM
Dibble, L.E *et al.* (38)	12-15	30-40 minutes	3	60-70%
Corcos, D.M *et al.* (39)	8 or 12	2 or 3	2	30-40% of 1RM for upper body exercises and 50-60% for lower body exercises

Abbreviations: RM, Repetition Max

Figure 1. Figure 1- PRISMA flow diagram of Study Selection Process.