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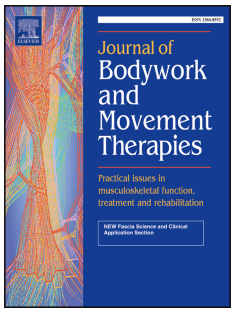

Is Pilates an effective rehabilitation tool? A systematic review

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Review Article

IS PILATES AN EFFECTIVE REHABILITATION TOOL? A SYSTEMATIC REVIEW

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ABSTRACT

Background: Pilates is a system of exercise focusing upon controlled movement, stretching and breathing. Pilates is popular today not only for physical fitness but also for rehabilitation programs. This paper is a review of the literature on the effectiveness of Pilates as a rehabilitation tool in a wide range of conditions in an adult population.

Methods: A systematic literature review was carried out according to the PRISMA guidelines. Electronic databases were searched for cohort studies or randomised controlled trials (RCTs), and inclusion and exclusion criteria were applied. The final RCTs were assessed using the PEDro and CONSORT 2010 checklists.

Results: Twenty-three studies, published between 2005 and 2016, met the inclusion criteria. These papers assessed the efficacy of Pilates in the rehabilitation of low back pain, ankylosing spondylitis, multiple sclerosis, post-menopausal osteoporosis, non-structural scoliosis, hypertension and chronic neck pain. Nineteen papers found Pilates to be more effective than the control or comparator group at improving outcomes including pain and disability levels. When assessed using the CONSORT and PEDro scales, the quality of the papers varied, with more falling toward the upper end of the scale.

Conclusion: The majority of the clinical trials in the last five years into the use of Pilates as a rehabilitation tool have found it to be effective in achieving desired outcomes, particularly in the area of reducing pain and disability. It indicates the need

for further research in these many areas, and especially into the benefits of particular Pilates exercises in the rehabilitation of specific conditions.

Keywords

Pilates, rehabilitation, systematic literature review, low back pain, ankylosing spondylitis, multiple sclerosis, post-menopausal osteoporosis, non-structural scoliosis, hypertension

INTRODUCTION

The American College of Sports Medicine (ACSM) 2011 Position Stand on exercise recommends regular "cardiorespiratory, resistance, flexibility, and neuromotor training" to maintain fitness and health. They cite numerous physical and mental health benefits from a variety of exercise (Garber et al 2011). The evidence for the benefits of Pilates as a form of exercise in healthy adults, although lacking in rigour, was found to be strong for improving flexibility and dynamic balance, and moderate for enhancing muscular endurance (Cruz-Ferreira et al 2011).

Pilates has recently been growing in popularity in rehabilitation programs, due to its perceived benefits in musculoskeletal disorders, as well as other conditions (Gallagher 2000, Anderson 2010, Dunleavy 2010, Royer 2013, Cruz-Ferreira A 2011). This development has occurred in an unregulated manner, as Pilates itself is not taught as a rehabilitative tool, and experts in rehabilitation are not necessarily Pilates experts.

In spite of these limitations, Pilates as a specific form of rehabilitative exercise may prove to be a useful tool for helping people improve physical function in varying stages of life and varying physical condition (Di Lorenzo 2011).

Originally called Contrology, Pilates was designed by Joseph Pilates as a form of low-impact exercise suitable for use by anyone, and was particularly popular amongst dancers for many years. Pilates described Contrology as a system which 'develops the

body uniformly, corrects wrong postures, restores physical vitality, invigorates the mind, and elevates the spirit' (PilatesMiller 1998).

More recently, Wells et al (Wells et al 2012) reported the six major components of Pilates as: centering, concentration, control, precision, flow, and breathing. Pilates has become a mainstream, low impact exercise with many perceived benefits; both physical (such as balance, flexibility, pain reduction, disability reduction) and psychological (improved mindfulness, improved affect) (PilatesMiller 1998, Küçükçakır et al 2013, Nóra Tolnai 2016). Pilates exercise can either be done with specialised equipment or 'apparatus', or as a floor-based exercise on a mat. There is an emphasis on control of the torso (PilatesMiller 1998), and in more contemporary practice, the development of the 'neutral spine' or using the abdominals to create an 'imprinted spine' (Wells et al 2012). With a shift in modern healthcare towards patient centered active management compared to a purely passive care model, there is a greater demand for physical exercises in the healthcare system in order to lower the financial burden of disease (Weiss et al 2003, Richardson et al 2010) and due to the evidence of its benefits in outcomes (2016, Kemmler et al 2010).

Exercise in general has been shown to be beneficial in rehabilitation. Not only does tailored exercise potentially improve each component of physical fitness (cardiorespiratory fitness, muscular strength and endurance, body composition, flexibility, and neuromotor fitness) (Garber et al 2011), research suggests that pain and functional activity can be improved by exercise in patients with disability, in the short to medium term and depending on the exercise (Bertozzi et al 2013, Ibai Lopez-de-Uralde-

Villanueva I et al 2016, Brown CK 2016, Ferreira G 2015, Landmark 2011, SmithGrimmer-Somers 2010, Roddy 2005, Slater 2016).

Bertozzi et al (Bertozzi et al 2013), for example, conducted a systematic review and meta-analysis on the benefits of therapeutic exercise for subjects with nonspecific neck pain. They found a significant acute and medium term overall effect size for reducing pain, and a medium term but not significant overall effect size in reducing disability. Smith and Grimmer-Somers (SmithGrimmer-Somers 2010) reviewed the evidence in the literature for the effectiveness of physiotherapy exercise programs on chronic low back pain (CLBP) and found that exercise programs are effective in reducing pain and reoccurrence rates for CLBP for up to 6 months after the end of treatment.

The benefits of exercise in preventing chronic pain are well documented, with many theories as to how these benefits may occur. Such benefits were well presented in a paper by Landmark et al (Landmark 2011). In a study on 46 533 subjects, they found a consistent association between the duration, intensity and frequency of recreational exercise and the prevalence of chronic pain in the general population. They suggest exercise has positive effects on both pain relief and psychological status or mood, and that there may be a common pathway operating. A study done in 2014 by Jones et al (Jones MD 2014) indicated that beyond the exercise induced hypoalgesia that occurs during exercise, exercise can also alter the long-term tolerance to pain. They were able to show that exercise does not alter the pain threshold but rather the tolerance to pain and that the effect was a systemic one in that although the exercise primarily targeted the legs, the pain tolerance was tested in the arm using a blood pressure cuff. Exercise

has also been found to reduce neuropathic pain by reducing inflammatory chemicals that trigger pain (Chen Y-W 2012, Leung 2016, Merriwether E 2016). Leung et al (Leung 2016) found that in mice, regular exercise for 8 weeks increased the prevalence of regulatory macrophages in the muscle, leading to a greater release of anti-inflammatory cytokines and a decreased release of proinflammatory cytokines. A commonly proposed mechanism of hypoalgesia is via the release of endocannabinoids and endogenous opioids following exercise, though research indicates that this is not the only mechanism operating (Hoeger Bement MK 2005, Hoeger Bement MK 2009, Hoffman MD 2004, Sparling 2003, Koltyn KF 2014). There has been research into the role of conditioned pain modulation as a secondary mechanism of hypoalgesia, whereby exercise acts as a conditioning pain stimulus, and activates the descending inhibitory pathways which causes a decreased response to further pain stimuli (Lemley KJ 2014, Geva N 2013, Ellingston L 2011). These studies suggest that exercise, regardless of its nature, may be beneficial in decreasing the intensity of pain across a variety of conditions by a number of mechanisms.

Existing literature reviews on the topic of the effectiveness of Pilates include the Natural Therapies Overview Report (Baggoley 2015) and the updated Cochrane Review (Yamato TP 2015). The former (Baggoley 2015) was a review of previous systematic reviews and were therefore limited to the papers and specific conditions included in those reviews. The authors found the evidence for Pilates to be inconclusive, with varying results and quality across the included studies. The report reviewed systematic literature reviews published between 2008 and 2013. The authors made comment of the number of conditions for which Pilates had been investigated but for which there was

no systematic review. The updated Cochrane Review (Yamato TP 2015) was a systematic review of randomised controlled trials published up to March 2014, with an update to include papers published up to June 2015. The Cochrane Review investigated only the effects of Pilates on low back pain.

It is the aim of this study to find the various conditions where Pilates has been studied as a rehabilitative tool and whether it has been beneficial. This research aims to provide an updated review of the literature across a wider range of conditions, thus giving an indication of where Pilates may be most effective in rehabilitation as well as areas for future research.

METHODOLOGY

A systematic literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al 2009). The following online databases were searched: PubMed, Scopus, Embase, Mantis, CINAHL, and PEDro. An example of the search strategy used in PubMed is displayed in Table 1. The search was carried out from the 13th of March to the 18th of April 2016.

Place table 1 here

Forward and reverse citation tracking was carried out from January 9 to January 11, 2017. Forward citation tracking of the included studies was carried out using PubMed. The references of each of the included studies were searched for trials meeting the inclusion criteria to be included in the final review. Grey literature was searched on the Australian New Zealand Clinical Trials Registry (ANZCTR) (ANZCTR) and the United States National Institutes of Health clinicaltrials.gov website (USNIH).

The inclusion criteria required that the instructor was certified; that traditional Pilates exercises were used; that the participants were diagnosed with their condition and were aged between 18 and 70 years. Participants had to be non-smokers due to the high rate of associated co-morbidities. Only randomised controlled trials (placebo controlled or a comparator) and cohort studies were included, and only English, full-text articles. A placebo control group was defined as a group which maintained their usual routine with no treatment or exercise prescribed, whilst a comparator control group had some other form of exercise or treatment which was compared to Pilates in terms of efficacy. There was no restriction on publication date.

Once references were extracted using the search terms, they were exported to a shared Endnote library. Two of the authors (KB and PJW) completed the search, the removal of duplicates, the analysis of titles and abstracts, and the screening of the full papers. Any differences in the analysis were sent to the third author (SW). The full papers were read and any papers not meeting the inclusion/exclusion criteria were removed.

Data was extracted from the papers and entered into a table for later analysis. This research assumes that the pathologies have been correctly diagnosed and, by including only trials where the instructor was certified, that standard Pilates exercises have been followed. The papers were assessed for quality and risk of bias, to evaluate the overall quality of available evidence. The risk of bias of each paper was assessed according to the Physiotherapy Evidence Database (PEDro) method of assessment. The papers were scored out of eleven to assess both their internal and external validity, but are reported out of 10 for internal validity only. We assessed the quality of the final articles using the Consolidated Standards of Reporting Trials (CONSORT) method of appraisal. The choice of the CONSORT method was based on its specific use for appraising RCTs when compared to the other available appraisal methods.

RESULTS

The search terms were entered into the following databases: PubMed (returned 70 results), Scopus (returned 6 results), Embase (returned 76 results), Mantis (returned 28 results), CINAHL (returned 88 results), and PEDro (returned 52 results). This search yielded a total of 320 results. Papers were then screened according to the PRISMA flowchart (see Figure 1).

Place figure 1 here

One hundred and twelve duplicates were manually removed from the library leaving 208 records. A further 164 records were removed, based on a screening of title and abstract according to the inclusion and exclusion criteria. The remaining 43 full texts were screened for adherence to eligibility criteria, from which 23 were removed. A total of 20 full text studies met all inclusion criteria and were included in the final review. From these 20 papers, forward citation tracking produced no further papers to include, whilst reverse citation tracking revealed a further 2 papers (Gagnon 2005, Quinn et al 2011) and a grey literature search revealed 1 further paper (Scollay 2016). These were then included in the final review. Though timeframe was not part of the inclusion criteria, the dates of publication were all in the last 11 years (2005 – 2016).

The search of trial registries (USNIH, ANZCTR) revealed a number of unpublished trials which may be of future interest. These trials investigated the use of Pilates in conditions such as temporomandibular disorders, neck pain, low back pain, and primary dysmenorrhea.

All 23 included papers were randomised controlled trials published in the last 11 years with most of them (19 of the 23) within the previous 5 years. There were 1120 subjects in total. The population of each study is described in Table 2 and the study characteristics are described in Table 3.

Place table 2 here

Place table 3 here

The results of the majority of the studies (19 out of the 23) indicated that Pilates was beneficial in improving outcome measures such as pain and disability compared to the control or comparator group. These improvements were shown to be either statistically or clinically significant, or both. Statistical significance has been described using probability statistics ($P<0.05$). Where the authors reported clinical significance, it was determined by the intervention group having reached or surpassed a predetermined change in the outcome measure used. This score was not described in the included papers as an odds ratio or relative risk, but was based upon a reference to other sources where the minimum change in score had been determined. These outcomes were commonly measured using questionnaires and VAS scales. Disability was included in many trials as a measured outcome in the form of questionnaires relating to ability to perform daily tasks such as lifting, self-care and walking, an example being the Oswestry Disability Questionnaire (Fairbank JC 2000). Of the remaining four papers, three (Mostagi et al 2015, Wajswelner et al 2012, Gagnon 2005) had equivocal results compared to the comparator, and one paper (Curnow et al 2009) was unclear in its results. The results for each condition are discussed below, and summarised in Table 4.

Low Back Pain (LBP)

Ten papers out of a total of fourteen (exceptions being Gagnon et al (Gagnon 2005), Mostagi et al (Mostagi et al 2015), Wajswelner et al (Wajswelner et al 2012), and Curnow et al (Curnow et al 2009)), found that the Pilates group performed better than the control or comparator group in their outcome measures by the end of the study. Two of the most common outcome measures used were pain and disability. Eight studies

(Anand et al 2014, Donzelli et al 2006, Lee et al 2014, Marshall et al 2013, Gladwell et al 2006, Miyamoto et al 2013, Natour et al 2015, Gagnon 2005) showed that the Pilates group had a statistically significant decrease in pain ($P<0.001$ to <0.05). Six studies reported disability as an outcome measure (Donzelli et al 2006, Marshall et al 2013, Miyamoto et al 2013, da Luz et al 2014, Gagnon 2005, Quinn et al 2011) and five found a statistically significant decrease in disability in the Pilates group ($P<0.01$ to <0.05) with the exception being Quinn et al (Quinn et al 2011). Five papers reported also on clinically significant changes in pain and disability. All five reported a clinically significant improvement in pain (Mostagi et al 2015, Marshall et al 2013, Miyamoto et al 2013, Natour et al 2015, da Luz et al 2014), with da Luz et al (da Luz et al 2014) and Marshall et al (Marshall et al 2013) also reporting a clinically significant improvement in disability.

Two papers (Lee et al 2014, da Luz et al 2014) compared mat to equipment Pilates rather than to a control, and both found a statistically significant improvement in the outcomes for both forms at the end of the trial and thus concluded that Pilates itself was beneficial. The two did however differ, in that da Luz et al (da Luz et al 2014) found the equipment Pilates more beneficial in the reduction of pain ($P<0.01$), while Lee et al (Lee et al 2014) found the opposite to be true, with the mat Pilates group showing a greater decrease in disability, and improvement in movement outcomes such as balance, (measured by standing on a Balance Performance Monitor) and measurement of the length of sway from neutral across a 30 second time period. The da Luz et al (da Luz et al 2014) paper reported that both groups showed a clinically significant improvement in the areas of pain and disability, with no significant difference between the groups. In

terms of quality, the da Luz et al (da Luz et al 2014) paper scored higher on the CONSORT scale (22/24 compared to 7/24), and on the PEDro scale for risk of bias (8/10 compared to 4/10).

Three papers(Mostagi et al 2015, Wajswelner et al 2012, Gagnon 2005) found Pilates no better than the comparator. Mostagi et al (Mostagi et al 2015) used generic physiotherapy exercises, including stationary cycling, trunk and lower limb stretching, spine mobilisation and trunk muscle strengthening; Wajswelner et al (Wajswelner et al 2012) used generic global exercises including stationary cycling, leg stretches, upper body weights, Theraband, Swiss ball and nonspecific, multidirectional floor exercises. Gagnon et al (Gagnon 2005) used mat exercises for lumbar stabilisation as directed by athletic trainers, exercise physiologists and a physical therapists. Two of these papers (Mostagi et al 2015, Wajswelner et al 2012) were of above average quality with both scoring 7/10 in the PEDro analysis, and 18/24 (Mostagi et al 2015) and 17/24 (Wajswelner et al 2012) on the CONSORT scale. Gagnon et al (Gagnon 2005) scored lower in both the PEDro analysis (5/10) and the CONSORT scale (12/24). Gagnon et al (Gagnon 2005) and Wajswelner et al (Wajswelner et al 2012) found that both the comparator and Pilates group showed significant improvements ($P=0.004$ and $P<0.01$ respectively) in their outcome measures, suggesting that Pilates may be effective, even if it is not more effective than their general exercise programme. Mostagi et al (Mostagi et al 2015) on the other hand found that there were no statistically significant improvements in either groups outcomes at the end of the trial, though the general exercise group showed a small clinical but not statistical improvement where the Pilates

group did not.

One paper (Curnow et al 2009) was difficult to compare to any other study. The authors created three groups in the trial, all having an aspect of Pilates in their programme. The results from the paper were difficult to analyse as they showed little congruity through the study and between groups. The paper had a low score on the PEDro bias analysis at 2/10, and 9/24 on the CONSORT scale.

Ankylosing Spondylitis (AS)

Altan et al (Altan et al 2012) compared Pilates to a control group who continued with normal routine. The study found that Pilates resulted in significant improvement in the BASFI (Bath Ankylosing Spondylitis Functional Index) at week 12 (P=0.031) and week 24 (P=0.007) compared to the control. Rosu et al (Roşu et al 2014) combined three programmes: Pilates, McKenzie and Heckscher. Rosu et al (Roşu et al 2014) showed significant improvement (P = 0.001) in all outcome measures for both groups. According to CONSORT, Altan et al (Altan et al 2012) scored 19/24 compared to 7/24 for the Rosu et al (Roşu et al 2014) study. On the PEDro scale, Altan et al (Altan et al 2012) scored 7/10 compared to Rosu et al at 5/10 (Roşu et al 2014).

Multiple Sclerosis (MS)

Both studies on MS (Guclu-Gunduz et al 2014, Kalron et al 2016) used physical therapy as a comparator. Guclu-Gunduz et al (Guclu-Gunduz et al 2014) found significant improvement with Pilates compared to physical therapy (P<0.05), whilst Kalron et al

(Kalron et al 2016) found improvement in both (P<0.05). Kalron et al (Kalron et al 2016) scored 7/10 in the PEDro bias analysis and 23/24 in CONSORT quality assessment, where Guclu-Gunduz et al (Guclu-Gunduz et al 2014) scored 5/10 in the PEDro assessment and 13/24 in CONSORT. Both papers found that Pilates related to a significant improvement in patient outcome measures (P<0.05).

Postmenopausal Osteoporosis (PMO)

Both studies on PMO (Küçükçakır et al 2013, Angın et al 2015) showed a statistically significant (P<0.05) improvement in pain and quality of life (both using the VAS and QUALEFFO-41 respectively) in the Pilates group compared to the control or comparator group (P<0.05 (Angın et al 2015), P<0.001 (Küçükçakır et al 2013)). Where the control group in the study by Angin et al (Angın et al 2015) showed no improvement across any outcomes, the comparator (thoracic extension exercises) in Kucukacakir et al (Küçükçakır et al 2013) showed a statistically significant improvement (P<0.001 to 0.005) for most outcomes, indicating it may be almost as effective as Pilates. Both studies were of similar quality. Kucukcakir et al (Küçükçakır et al 2013) scored 6/10 on the PEDro Scale and 15/24 in CONSORT compared to 5/10 and 13/24 respectively in the Angin et al (Angın et al 2015) study.

Non-structural Scoliosis (NSS)

The one paper on NSS included (Alves de Araújo et al 2012) scored 13/24 in the CONSORT assessment and 5/10 in the PEDro bias assessment. The paper showed

improvement in all three outcome measures; Cobb angle, trunk flexion and pain, compared to the control group (P= 0.0001).

Hypertension (HT)

The study on HT (Martins-Meneses et al 2015) was of average quality (16/24 CONSORT, 4/10 PEDro). The study found that the Pilates group showed significant improvement (P<0.05) in all outcome measures compared to the control. The authors also reported a clinically significant decrease in blood pressure.

Chronic Neck Pain

The study on chronic neck pain (Scollay 2016) found a clinically and statistically significant improvement in the Pilates group in all outcome measures, including pain, disability and quality of life. They found that the comparator group of home exercise also improved in all outcome measures, but to a lesser extent than the Pilates group. The study scored 6/10 on the PEDro scale and 20/24 on the CONSORT checklist.

Place table 4 here

Comparison of Risk of Bias across the Studies

There were 19 studies that scored above 5/10 on the PEDro scale, indicating a low level of bias (see Figure 2). Two of the studies scored 4/10, indicating a moderate to high level of bias.

Place figure 2 here

Comparison of Quality Assessment across the Included Studies:

Nineteen of the 23 papers met more than half of the CONSORT items with only 4 papers scoring lower than 12/24 (see Figure 3). Scores ranged from a minimum of 7 and maximum of 23.

Place figure 3 here

DISCUSSION

From the limited data available, it would seem from the statistically and clinically significant findings that Pilates has demonstrated efficacy as a tool for the rehabilitation of a wide range of conditions. Common improvements across the different conditions were in pain, disability, and balance or functional movement outcomes. However, aside from LBP, there were too few studies to draw conclusions as to the usefulness of Pilates for relieving symptoms for specific conditions. Heterogeneity of study protocols for Pilates intervention and outcome measures further increase the difficulty for comparing the effectiveness of Pilates for specific conditions. Whether results were clinically significant in addition to statistical significance was not reported in all studies, making it difficult to determine the clinical relevance of the study's results. Those studies that did report on clinical significance determined this based upon external sources, rather than stating an odds ratio or relative risk, which would have allowed for more meaningful interpretation of results.

Though the data is limited, the quality is reasonable, with the distribution of the PEDro and CONSORT scores biased to the upper end of the scale. When looking specifically at those studies with the higher PEDro scores (7/10 or higher), and therefore the greatest internal validity we found that all except Mostagi et al (Mostagi et al 2015) reported a significant improvement in the Pilates group. Two of these papers using a comparator (Wajswelner et al 2012, Kalron et al 2016) found that the Pilates group showed a significant improvement, but the between-group difference was not significant. Those papers using a control (Altan et al 2012, Miyamoto et al 2013, Natour et al 2015, Quinn et al 2011) as well as Marshall et al (Marshall et al 2013), which compared Pilates to stationary cycling, reported a significant difference between groups in favour of the Pilates group. These studies could indicate that Pilates is effective in achieving desired outcomes, if not always more so than other forms of exercise.

The Natural Therapies Overview Report (NTOR) (Baggoley 2015) and the updated Cochrane Review (Yamato TP 2015) reported results different in some respects to this paper. The Cochrane Review (Yamato TP 2015) found that there was evidence for the use of Pilates in low back pain, to reduce pain and disability, but the quality of the evidence was low. Interestingly, the more recent and higher quality papers more commonly found Pilates to have a positive effect, which is in agreement with the findings of this paper. The authors found that there were no reports of adverse events and that there was some reduction in pain and functional improvement in the area of LBP, but these were in the short term, with no investigation into long term results.

The Natural Therapies Overview Report (NTOR) was limited to an earlier timeframe (between 2008 and 2013) and the conditions that were included in the systematic

reviews they included(Baggoley 2015). They found major limitations in the studies included in their review. There was a high risk of bias, poor reporting of limitations and small sample sizes. Although this appears in contrast to some of the findings of this paper, in fact it relates well, because two of the four papers included in this study which were published prior to 2012, and therefore included in the NTOR review, received the lowest scores on the PEDro checklist. The quality of the studies in the last ten years has improved. Moreover, 17 of the 22 studies were found to adequately report limitations, and that while sample sizes were small, the 7 studies that reported performing a power calculation found the population size to remain adequate throughout the course the studies.

While there are limited studies in this area, those reviewed in this study would indicate that it is an area of research worth pursuing. It would be useful to study the benefits of particular Pilates exercises in the rehabilitation of specific conditions. These results could aid in clinical decision making with regards to which exercises may be most beneficial for a particular patient, and those which may be less so. This would be particularly applicable in the area of LBP, where there is already a reasonable level and quantity of evidence to suggest that Pilates in general is beneficial, it may now be useful to specify exactly what aspect of Pilates has the best results.

LIMITATIONS

The main limitation found was the small number of conditions represented in the literature, and very few studies into conditions other than LBP. Across all conditions there was a lack of uniformity in study quality, controls or comparators used, Pilates exercises prescribed and study methodology. This made it difficult to compare the studies, perform a meta-analysis and analyse their significance.

A limitation across all included papers was short study periods and limited follow up data. Most intervention periods were between 6 and 8 weeks, though four papers (Küçükçakır et al 2013, Donzelli et al 2006, Roşu et al 2014, Angın et al 2015) had interventions ranging from 24 weeks to 1 year. The follow up periods varied, and the results following the longer periods varied, with Miyamoto et al (Miyamoto et al 2013) finding that the between group differences were no longer statistically significant at 6 months, whereas Wajswelner et al (Wajswelner et al 2012) found that the improvement in outcome measures was maintained at 24 weeks.

None of the papers included in this study had any data on the economic advantages or disadvantages of Pilates, or an analysis as to how it may compare to another modality in terms of patient costs. Similarly, there was no comparison made in any paper of recommended rate of servicing in order to produce beneficial results. This information would provide better information as to the viability of Pilates in long term conditions such as those investigated in these studies. Finally, it behooves authors to specifically address adverse events, and only 5 studies did make mention of this. One paper (Scollay 2016) made mention of two participants discontinuing the trial due to worsening

symptoms, though made no comment on whether this change was a result of the trial. Absence of reference to adverse events does not mean none occurred, and if no adverse events occurred it should be stated in the results.

CONCLUSION

The majority of the clinical trials in the last five years into the use of Pilates as a rehabilitation tool have found it to be effective in achieving desired outcomes, particularly in the area of reducing pain and disability. This latest research has also rated reasonably well in terms of quality, using the PEDro scale and CONSORT method of appraisal. This study updates the systematic reviews of the literature done earlier, and uniquely shows the improvement in the research in the last 5 to 10 years, and in addition it covers a broader range of conditions studied. It indicates the need for further research in these many areas, and especially into the benefits of particular Pilates exercises in the rehabilitation of specific conditions. Future research could aim to improve the uniformity of study methodology and exercises prescribed in order to draw more meaningful conclusions when comparing results of multiple studies. This study revealed the need for researchers to specifically state whether or not any adverse events had occurred during the course of their studies, and to increase the follow up period of investigation in their outcomes.

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TABLES

Table 1. The Search Strategy used in PubMed as an example of the search terms used to extract the relevant literature.

(Pilates) OR (Pilate) AND
(disease) OR (injury) OR (illness) OR (back pain) OR (pain) OR (neck pain) OR (Parkinson's) OR (Multiple Sclerosis) OR (MS) OR (Ankylosing Spondylitis) OR (COPD) OR (Rheumatoid arthritis) OR (Cystic Fibrosis) OR (stroke) OR (hypertension) OR (diabetes) OR (diabetes mellitis) OR (postpartum) or (postmenopausal) OR (arthritis) AND
(Random* controlled trial) OR (Clinical trial) OR (random allocation) OR (controlled trial) OR (control group)

Table 2: The number of papers and total number of subjects per each condition included in the systematic literature review.

Condition	Number of Papers	Number of Subjects (total)
Chronic Low Back Pain	14	708
Ankylosing Spondylitis	2	151
Multiple Sclerosis	2	71
Post-menopausal Osteoporosis	2	111
Non-structural Scoliosis	1	31
Hypertension	1	44
Chronic Neck Pain	1	24

Table 3: Study Characteristics, iteming the type of study, subjects included in the research, the intervention and control/comparator, the intervention period and whether there was a follow-up of outcomes.

Author	Type of Study	Populations/age	Intervention (subject number)	Control/Comparator (subject number)	Intervention period	Follow-up assessment
Albert 2014 (Anand et al 2014)	RCT	CNLBP age 18-60	Modified specific Pilates based exercises with flexibility exercises (15)	Therapeutic exercises with flexibility exercises (15)	8 weeks	N/A
Altan 2012 (Altan et al 2012)	RCT	AS, age 28-69. 30 women, 25 men	Pilates (30)	Normal routine (25)	12 weeks	24 weeks
Alves 2012 (Alves de Araújo et al 2012)	RCT	Female Physiotherapy Students with non-structural scoliosis, age 18-25	Pilates (20)	No therapeutic intervention (11)	12 weeks	N/A
Angın 2015 (Angın et al 2015)	RCT	Women with Post-Menopausal Osteoporosis, age 40-69	Pilates (22)	Normal routine (19)	24 weeks	24 weeks
Curnow 2009 (Curnow et al 2009)	RCT	CLBP	Everyone taught four basic Pilates exercises. Group B (14) and C (12) received a relaxation posture on a specifically designed spinal support to	Group A only received the four Pilates exercises. (13)	6 weeks	8 weeks

			use before the basic exercises. Group C also received a postural training exercise to perform after the basic exercises			
da Luz 2014 (da Luz et al 2014)	RCT	CNLBP, age 18-60	Equipment Pilates (43)	Mat Pilates (43)	6 weeks	6months
Donzelli 2006 (Donzelli et al 2006)	RCT	CNLBP, age 20-65	Pilates (21)	Back School programme (22)	10 sessions then at home for 6 months	1,3 and 6 months
Gagnon 2005 (Gagnon 2005)	RCT	LBP	Clinically necessary treatment plus Pilates (6)	Clinically necessary treatment plus Traditional Therapeutic Exercise (6)	Prescribed as clinically necessary	Every 4th treatment and at discharge
Gladwell 2006 (Gladwell et al 2006)	RCT	CNLBP, age 18-60	Pilates (25)	Normal routine (24)	6 weeks	N/A
Guclu-Gunduz 2014 (Guclu-Gunduz et al 2014)	RCT	MS, age 27-45	Pilates (18)	Physical Therapy (8)	8 weeks	N/A
Kalron 2016 (Kalron et al 2016)	RCT	MS, age 25-55	Pilates (22)	Standardized Physical Therapy (23)	12 weeks	12 weeks

Küçükçakır 2013 (Küçükçakır et al 2013)	RCT	Postmenopausal Osteoporotic Women, age 45-65	Pilates (35)	Home Exercise of thoracic extension (35)	1 year	1 year
Lee 2014 (Lee et al 2014)	RCT	Business Women with CLBP	Mat Pilates (20)	Apparatus Pilates (20)	8 weeks	N/A
Marshall 2013 (Marshall et al 2013)	RCT	CNLBP, age 18-50	Pilates (32)	Stationary Cycling (32)	8 weeks	6 months
Martins 2015 (Martins-Meneses et al 2015)	RCT	Women using antihypertensive medications, age 30-59	Mat Pilates (22)	Normal routine with no exercise training (22)	16 weeks	1 month, 4 months
Miyamoto 2013 (Miyamoto et al 2013)	RCT	CLBP, age 18-60	Modified pilates plus educational booklet on LBP (43)	Educational booklet on LBP only (43)	6 weeks	6 months
Mostagi 2015 (Mostagi et al 2015)	RCT	CLBP, age 18-55	Pilates (11)	General Exercises (11)	8 weeks	12 weeks
Natour 2015 (Natour et al 2015)	RCT	CLBP, age 18-50	Pilates plus maintained treatment with NSAID (30)	Continued treatment of NSAID with no other intervention (30)	90 days	46 90 180 days
Patti 2016 (Patti et al 2016)	RCT	CLBP, age 28-54	Pilates (19)	Social Program (19)	14 weeks	14 weeks
Quinn 2014 (Quinn et al 2011)	RCT	CLBP, age 21-60	Pilates (10)	No Intervention (10)	8 weeks	N/A

Roşu 2014 (Roşu et al 2014)	RCT	AS	Kinetic Program and Pilates, McKenzie and Heckscher exercises (48)	Kinetic Program (48)	48 weeks	N/A
Scollay 2016 (Scollay 2016)	RCT	Chronic Neck Pain, age 18-58	Equipment Pilates and home-based exercise (15)	Home-based exercise only (9)	8 to 10 weeks	Weeks 4, 9 and 12
Wajswelner 2012 (Wajswelner et al 2012)	RCT	CLBP, age 32-64	Pilates (44)	General Exercise (43)	6 weeks	12 and 24weeks

CNLBP = chronic non-specific low back pain

CLBP = chronic low back pain

LBP = low back pain

AS = ankylosing spondylitis

MS = multiple sclerosis

Table 4: Details of Study Outcome Measures and Results.

	Outcome Measures	Results Summary	Comments
Albert 2014 (Anand et al 2014)	Oswestry Disability Index and VAS.	Modified specific Pilates based exercises helped to reduce pain (mean 3.93 SD 0.92), improve back specific function (mean 41.36 SD 2.10), improve healthy, personal care, social life and flexibility more than the therapeutic exercise.	
Altan 2012 (Altan et al 2012)	Functional capacity, measured with the Bath Ankylosing Spondylitis Functional Index (BASFI). Exploratory outcome measures were Bath Ankylosing Spondylitis Disease Activity Index (BASDAI), Bath Ankylosing Spondylitis Metrology Index (BASMI), Chest expansion, and Ankylosing Spondylities Quality Of Life (ASQOL) questionaire.	Pilates group had significant improvement in BASFI at week 12 (P=0.031) and 24 (P=0.007) compared to control which had no significant change. Overall the Pilates group showed significantly superior results at week 24 (P=0.023).	
Alves 2012 (Alves de Araújo et al 2012)	Cobb angle, range of motion and pain.	The intervention group showed a significant decrease in Cobb angle (P=0.0001), significant increase in trunk flexion (p=0.0001), and a significant reduction in pain (P=0.0001). The control group showed no significant change from in Cobb angle, pain or trunk flexion. The effect size between the groups was 0.65 for Cobb angle, 1.1 for trunk flexion and 0.80 for pain.	
Angin 2015 (Angın et al	Lumbar BMD, physical performance, VAS and QUALEFFO-41 for quality of life.	BMD values increased in the Pilates group (P<0.05) but decreased in the control with a significant difference between the two (P<0.05). Physical performance	

2015)		increased in the Pilates group (P=<0.05) and showed no change in the control. Significant increases in all parametres of the QOL in the Pilates vs control which decreased (P<0.05) in some parameters. Pain levels were significantly decreased after the exercise in the Pilates group (P=<0.05) with no change in the control.	
Curnow 2009 (Curnow et al 2009)	Oswestry Disability Questionnaire, a Stork test, and recorded their average frequency (using Scheffe and Fisher), intensity and duration of their back pain over a week.	Oswestry Disability Questionnaire only had one statisically significant change with Group B reporting significantly less pain post exercise than before in response to question one ("Do you have back pain at present") (P=0.013). Group B showed significant differences using Sheffe to analyse frequency (P=0.0001), while group C showed significant differences by week shown when using fisher (P<0.05). Some of the frequency improvements were lost once exercise ceased in week 6. For duration all groups showed a reduction in duration of episodes with some members of each group being pain free at week 8. Group B and C were higher in proportion (30.8% and 25% respectively compared to group A 7.7%) but not significantly so. Some improvements were lost when exercise ceased in week 6. All groups experienced a mean reduction of intensity of pain, but Group B showed a significantly greater reduction of intensity than group A (P=0.02).	In the baseline testing the authors used the Stork test as a measure of stability. However when performing tests at the completion of the study the authors found that the results were altered dramatically by the initial stance of the patient at the beginning of the test. As this was not accounted for at baseline the author chose to remove the Stork test from the study outcomes.
da Luz 2014 (da Luz et al 2014)	Primary: Pain intensity and Disability. Secondary global perceived effect, patient specific disability and kinesiophobia.	After 6 months there was a significant difference for disability and specific disability and kinesiophobia in favour of equipment based Pilates (P<0.01). No other differences were found between the remaining outcomes.	

Donzelli 2006 (Donzelli et al 2006)	Oswestry Low Back Pain Disability Scale (OSBPDQ) and VAS.	Both groups experienced a significant reduction in pain and disability. Pilates showed better compliance and subjective response to treatment.	The results did not include any P values or standard deviation values.
Gagnon 2005 (Gagnon 2005)	VAS, Oswestry Disability Index, Lumbar spine AROM measures in flexion and extension, stability platform measures of central balance	Both groups showed significant improvements in the VAS (P=0.004), Oswestry Disability Index (P=0.004) and central balance (P=0.013)	As the duration, frequency and nature of the treatments were determined by clinical requirements rather than dictated by study design there was little congruity between individual results.
Gladwell 2006 (Gladwell et al 2006)	Pain was measured by a Roland Morris Visual Analogue Scale (RMVAS). Oswestry Low Back Pain Disability Questionnaire (OSWDQ) measured limitation of various ADLs. SF-12 measured general health. Subjective Improvement was measured by a symptom report. Sports functioning was measured by a sports functioning questionnaire. Physiological functioning was measured by the stork test and the sit-and-reach test.	Pilates group improved in general health ($P<0.05$), sports functioning ($P<0.05$), flexibility($p<0.05$), proprioception($P<0.05$) and decreased pain ($P<0.05$). Control group showed no change.	The authors were not specific about what questionnaire was used for subjective improvement or sports functioning and thus make the study difficult to reproduce.
Guclu-Gunduz 2014 (Guclu-Gunduz et al 2014)	Balance and mobility was measured with Berg Balance Scale, Timed up and go test. Upper and lower muscle strength was measured with a hand-held dynamometer. Confidence in balance skills while performing ADLs was measured with Activities Specific Balance Confidence Scale.	Improvements were observed in balance, mobility, and upper and lower extremity muscle strength in the Pilates group (all $P<0.05$). The physical therapy group had no significant difference in any outcome measures.	

Kalron 2016 (Kalron et al 2016)	Spatio-temporal parametres of walking and posturography parametres during static stance. Time Up and Go Test, 2 and 6 minute walk test, functional reach test, Berg Balance Scale, Four Square Step Test. The Multiple Sclerosis Walking Scale and Fatigue Impact Scale.	Both groups significantly improved their centre of pressure path length (P=0.034) and sway rate with eyes open (P=0.039). Both groups increased their walking speed (P=0.021) and mean step length (P=0.023) and mean single support phase (P=0.008). Both groups decreased their mean step time (P=0.009) and time when both legs were in contact with the floor (P=0.002). No changes were observed in cadence and stride width. Both groups performed better in timed up and go test (P=0.023) and in the self reported walking abilities (P=0.042) but no change in the level of perceived fatigue (P=0.226).	
Kucukcakir 2013 (Küçükçakır et al 2013)	VAS, 6 minute walking, sit-to-stand test, QUALEFFO-41 Questionnaire, SF-3. Patients were also asked to report the number of falls during the intervention.	A significant improvement was noted in all parameters in the Pilates group (all P<0.001). Except for Qualeffo- Leisure time activities (P=0.152), SF-36 physical role limitation (P=0.336) and emotional role limitation (P=0.258) subclass, a significant improvement was noted in all other parameters in the home exercise group (P=<0.001 to 0.005).	
Lee 2014 (Lee et al 2014)	Sway length and velocity was measured on a Balance Performance Monitor standing for 30 seconds with eyes open, and VAS.	Both groups significantly improved in all parameters (P<0.05), but the mat Pilates group showed a greater improvement than the apparatus group (P<0.05).	
Marshall 2013 (Marshall et al 2013)	VAS, Oswestry Low Back Pain Disability Index version 2, Pain Catastrophising Scale, Fear Avoidance Beliefs Questionnaire (FABQ).	Disability was significantly lower in the Pilates group (P<0.05). Pain was reduced in both groups (P<0.05) but was lower for the Pilates group. FAB scores were the same between groups. Similar results in the catastrophizing survey between the two	

		groups.	
Martins 2015 (Martins-Meneses et al 2015)	Clinical and ambulatory blood pressure, heart rate, and double product. Body mass, height, BMI, waist and hip circumferences, flexibility and right and left hand strengths.	The Pilates group had significant improvements within and between groups for the systolic, diastolic and mean blood pressure in all moments evaluated (clinical, 24hr, awake and asleep) (all $P<0.05$). The Pilates group also had significant improvements in height, waist and hip circumferences, flexibility, right and left hand strengths and clinical double product (all $P<0.05$). The control group showed no significant changes.	
Miyamoto 2013 (Miyamoto et al 2013)	Primary Outcomes: Pain Numeric Rating Scale, Roland-Morris Disability Questionnaire. Secondary Outcomes: Patient-Specific Functional Scale, Global Perceived Effect Scale and Tampa Scale for Kinesiophobia.	The Pilates group showed significant improvement in pain (mean difference 2.2 points 95%CI 1.1-3.2), disability (mean difference 2.7 95%CI 1.0-4.4) and global impression of recovery (mean difference -1.5 95%CI -2.6 to -0.4) compared to the control group after the intervention, but these differences were no longer statistically significant at 6 months.	
Mostagi 2015 (Mostagi et al 2015)	Primary Outcome: VAS. Secondary Outcome: Functionality (Quebec Back Pain Questionnaire), Flexibility (Sit and Reach test), Trunk Endurance (Sorenson Test).	The general exercise group improved significantly over the study in functionality ($P=0.02$ at end of study and $P=0.04$ at follow up). The general exercise group also had improved flexibility at follow up ($P=0.01$). The Pilates group showed no differences over the period of the study.	
Natour 2015 (Natour et al	VAS (pain), Roland Morris questionnaire (function), SF-36 (quality of life), Likert Scale (satisfaction with treatment), Sit and Reach Test	The Pilates group improved significantly with pain ($P<0.001$), function ($P<0.001$) and quality of life domains of functional capacity ($P<0.046$), pain (0.010) and vitality	

2015)	(flexibility) and NSAID intake.	(P<0.029). The Pilates group was also found to take fewer NSAIDs than the control (P<0.010).	
Patti 2016 (Patti et al 2016)	Posturography and Oswestry Disability Index.	Posturography improved significantly in the Pilates group both with eyes open and closed (P<0.05), with no change in the comparator group. Both groups performed better in the Oswestry Disability Index but to a greater extent in the Pilates group (P<0.001 compared to P<0.01).	
Quinn 2011 (Quinn et al 2011)	VAS (pain), Roland Morris Disability Questionnaire (disability), Sahrmann Abdominal Test (SAT) (lumbopelvic control)	The intervention group improved in pain by a mean of 9.5mm (range -16 to 45mm) on the VAS score at follow up. The placebo group deteriorated by a mean of 4.7mm (range -35 to 24mm). There was a significant between group difference (P=0.047). The mean disability scores improved slightly in the intervention group of 1.47 compared to the mean improvement of 0.21 in the control group but this was not statistically significant (P=0.301). After analysis 27% of the intervention group passed the SAT test for lumbopelvic control compared to 0 participants at baseline and none of the control group.	

Rosu 2014 (Roşu et al 2014)	Pain, modified Schober test (mST), finger-floor distance (FFD), chest expansion (CE), vital capacity (VC), Bath Ankylosing Spondylitis Disease Activity Index(BASDAI), Bath Ankylosing Spondylitis Functional Index (BASFI) and Bath Ankylosing Spondylitis Metrology Index (BASMI).	The Kinetic program demonstrated significant improvement in all AS parameters in both groups (P=0.001). The intervention group however showed significant improvement in pain, mST, FFD, BASFI, BASDAI and BASMI. Both groups significantly improved in CE but the parameter increased significantly in the intervention group (P=0.011). VC did not change significantly through the study but there was a significant difference between the groups with the intervention group showing a greater change (P=0.127 compared to P=0.997).	
Scollay 2016 (Scollay 2016)	VAS (pain), NPQ (disability), SF-36 (quality of life) and CEQ and yellow flag correlations.	Both groups showed significant reductions in pain at all intervals with the largest change at week 12 in the Pilates group (49.2% decrease in the VAS with a 95% confidence interval and P<0.001). In pain, 53% of the Pilates group reached the minimum change necessary for clinical significance by week 9, and 71% by week 12. It was reached by 55.6% of the comparator group by week 9 and the same at week 12. Both groups improved in NPQ at all intervals, with the largest difference in the Pilates group from baseline to week 12 (mean decrease 50% with 95% confidence interval and P<0.001). Clinical significance was reached by 60% of the Pilates group by week 9 and 71% by week 12. It was reached by 58% of the comparator group by week 9 and the same at week 12. Both groups improved in quality of life scores though not all items were statistically significant.	

		The Pilates group showed no significant correlation between baseline CEQ or yellow flag scores and changes in any of the outcomes for weeks 9 or 12.	
Wajswelner 2012 (Wajswelner et al 2012)	Primary Outcome: Pain/disability on the Quebec Scale. Secondary Outcome: numeric rating, Patient-Specific Functional Scale, Pain Self-Efficacy Questionnaire, quality of life, and global perceived effect of treatment.	At 6 weeks no difference was found between the two groups for the Quebec Scale with both groups showing significant improvements (P=0.07). Similar results were found at 12 and 24 weeks for the secondary outcome measures perceived pain (P=0.38) or perceived function (P=0.81).	

FIGURES

Figure 1: Documentation of Screening Methods using the PRISMA Flowchar

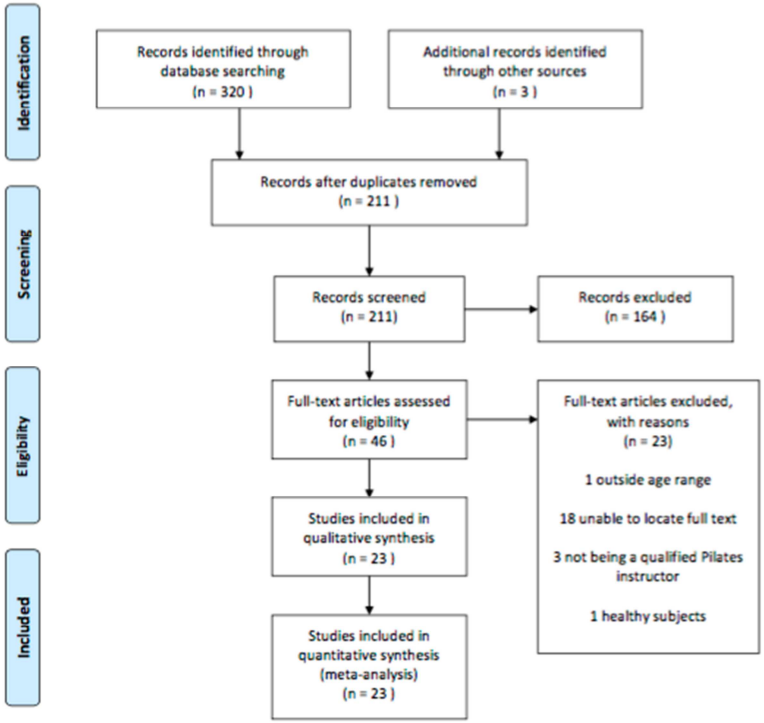

Figure 2: PEDro Criteria for Assessment of Bias

	Albert	Altan	Alves	Angin	Curnow	da Luz	Donzelli	Gagnon	Gladwell	Guclu-Gunduz	Kalron	Kucukcakir	Lee	Marshall	Martins	Miyamoto	Mostagi	Natour	Quinn	Patti	Rosu	Scollay	Wajswelner
Eligibility Criteria		☺	☺	☺		☺	☺	☺	☺	☺	☺		☺	☺	☺	☺	☺		☺	☺	☺	☺	☺
Random Allocation	☺	☺	☺	☺	☺	☺		☺	☺		☺	☺	☺	☺		☺	☺	☺	☺	☺	☺	☺	☺
Concealed Allocation	☺	☺	☺			☺					☺			☺		☺	☺	☺	☺				☺
Baseline Comparability		☺	☺	☺		☺		☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺
Subject Blinding																							
Therapist Blinding																							
Assessor Blinding	☺	☺				☺	☺		☺		☺	☺				☺	☺	☺	☺	☺			
Adequate Follow Up		☺		☺		☺				☺	☺	☺		☺				☺		☺	☺		☺
Intention to Treat Analysis						☺		☺		☺				☺	☺	☺	☺	☺	☺	☺		☺	☺
Between-Group Comparison	☺	☺	☺	☺	☺	☺		☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺		☺	☺	☺
Point Estimates and Variability	☺	☺	☺	☺		☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺		☺	☺	☺
Total /10	**5/10**	**7/10**	**5/10**	**5/10**	**2/10**	**8/10**	**2/10**	**5/10**	**5/10**	**5/10**	**7/10**	**6/10**	**4/10**	**7/10**	**4/10**	**7/10**	**7/10**	**8/10**	**7/10**	**5/10**	**5/10**	**6/10**	**7/10**

Figure 3: CONSORT Quality Assessment.