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REVIEW ARTICLE

Effectiveness of Pilates Exercise on Quality of Life in Older Adult Women: A Scoping Review

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Abstract

This scoping review investigates the effects of Pilates exercise interventions on health and quality of life of older adult women. Through a comprehensive examination of existing literature, this scoping review identified key areas where Pilates has shown to significantly benefit physical capabilities such as strength, balance, and flexibility, alongside mental health improvements, including reduced symptoms of depression and anxiety, and enhanced sleep quality. Thus, this scoping review emphasizes a possible role of Pilates in addressing age-related physical and psychosocial challenges, and suggests it as suitable low-impact exercise for promoting healthy aging. Despite the methodological heterogeneity among studies, the overall evidence suggests that Pilates may be a valuable component of geriatric healthcare strategies. The findings advocate for further research to expand the evidence and further guiding healthcare professionals in integrating Pilates into exercise prescriptions for older adult women.

Keywords: ageing · older adults · Pilates exercise · women's health

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Introduction

The global population is witnessing a significant transformation marked by a steady increase in the proportion of older adults. It is projected that by 2050, the number of individuals aged 80 years or above will grow significantly, potentially reaching 434 million (Eurostat, 2020). On a world scale, the number of people aged over 60 is increasing at a yearly rate of 3%, far higher than the younger age groups. Consequently, it is expected that older adults will make up around 22% of the total population by mid-century. (WHO, 2021; Navaneetham and Arunachalam, 2023). This demographic evolution has a strong social, political, and economic impact (European commission, 2023: Osareme et al., 2024) and calls for improvements in healthcare and longevity strategies (Melo Pereira et al., 2022).. This demographic shift brings to the forefront the urgency of promoting well-being and health and enhancing the quality of life for older adults. Ageing is linked to cellular and systemic decline, impacting physical and psychosocial health (Długosz-Boś M. et al, 2021; Lima M. et al., 2021).

Women frequently encounter distinct challenges concerning their physical health and psychological well-being as they advance in age. Social changes, such as the "empty nest" phase, can lead to shifts in identity, sense of purpose, and social roles, often compounding the physical and mental health challenges associated with aging (Mattioli et al., 2022; Cheng et al., 2019). These transitions are further exacerbated by age-related physiological changes, including decreased bone density, reduced muscle mass, and increased risk of chronic diseases (Larsson et al 2019). Additionally, psychological stressors like social isolation, loneliness, and anxiety are prevalent among older women, potentially leading to a decline in mental health (Nicholson, 2014; Hawkley et al, 2010).

Physical activity plays a crucial role in decelerating the speed of this decline, raising or maintaining the intrinsic and functional capacity by improving physical capacities (e.g., strength, balance, and flexibility) also with advanced age (Wang YR et al., 2023 Chodzko-Zajko W. et al, 2019; McPhee JS et al., 2016). In this context, physical activity can represent one of the pivotal factors for maintaining and improving overall health in the older adults as it mitigates the influence of aging on the loss of bio-psychosocial function, promoting independence and a higher quality of life for older adults. (Pucci G.C. et al, 2021). Among the diverse array of exercise modalities available, Pilates has received increasing attention for its holistic approach to fitness, emphasizing core strength, flexibility, posture, and mind-body connection (Meikis L et al., 2021; da Silva LD et al., 2021; Penelope, L., 2002). Originating in the 1920s by Joseph Pilates, this method has shown benefits across various demographics, including athletes, individuals with chronic conditions, younger adults and older adult population (Moreno-Segura N. et al., 2018; Fleming K.M. et al., 2018). However, there remains a need to further investigate its effects specifically on older women to determine its full range of benefits in this demographic.

As women age, they are confronted with physiological changes such as muscle loss, decreased bone density, reduced flexibility, and compromised balance, all of which can contribute to an increased risk of falls, fractures, and functional limitations (Rodríguez-Gómez I et al., 2019; Guccione, A. et al., 2005; Błaszczyk, J. et al., 2014). Pilates, with its low-impact exercises focusing on controlled movements, breathwork, and alignment, offers an effective means that can help address these age-related challenges and brings an improved physical and mental well-being in older adult women. Pilates exercise programs have shown to bring improvements in many areas that affect the quality of life in older adult women, such as sleep quality, anxiety, depression, and fatigue (Ravari A. et al., 2021; Aibar-Almazán A, et.al., 2019), in hormone levels, cardiorespiratory fitness (Fernández-Rodríguez R et al., 2019) and psychological function (Farzane and Koushkie Jahromi , 2022), in fall prevention and functional balance (Cruz-Díaz D. et al.,, 2015; Mesquita LS et al., 2015; Hyun J. et al., 2014; Carrasco-Poyatos M. et al., 2019). Despite these promising findings, to the best of our knowledge, no scoping review to date has been conducted to compile and analyze all available evidence on the effectiveness of Pilates for older adult women.

This paper aims to fill this gap by examining the effects of Pilates-based interventions on the overall health of older adult women. Our objective is to shed light on the potential benefits of Pilates that may offer as a tailored and effective exercise strategy for promoting healthy aging and improving the physical and psychological quality of life for this population.

Method

This paper is a scoping review focusing on the potential of Pilates for improving quality of life in older adult women. This article is a scoping literature review, with no new empirical data collected with human participants or animals.

Therefore, ethical approval was not sought. The scoping review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist (Tricco et al., 2018).

Inclusion and exclusion Criteria

Study inclusion criteria were structured according to PICOS tool.
Population (P): Older adult women (years 55 and over).
Intervention (I): Pilates-based exercise interventions.
Comparisons (C): Control groups, receiving no intervention or other exercise programs.
Outcomes (O): Outcome variables broadly related to quality of life in older adult women.
Study design (S): Randomized controlled trials and non-randomized clinical trials.
Studies were excluded if they involved mixed-gender populations without separate subgroup analysis for women, participants younger than 55 years, or if they lacked any interventional component (i.e., purely observational or theoretical). In addition, studies that did not report outcomes related to quality of life or its specific domains were excluded from the final synthesis.

Search strategy

Multiple databases of scientific literature (PubMed, PEDro and Scopus) were searched in November 2024 without regard to the date of publication. The following Boolean search string was used in PubMed (with syntax adapted as needed based on the database requirements): *(pilates AND (elderly women OR older women))*. Additionally, reference lists of several review articles describing interventions for older adults were carefully scrutinized. Finally, we carefully reviewed reference lists of all articles that were already retrieved through the database search and were published within the last 4 years.
Upon eliminating duplicate entries, the authors individually screened titles and abstracts based on pre-established eligibility criteria. Articles that satisfied these criteria underwent full-text examination in the subsequent phase. An article was included if both reviewers confirmed its eligibility. Any disagreement between the reviewers was resolved through discussion and consulting the third author. Two authors also assessed the full-texts, and any potential disagreements were similarly resolved by additional discussions.

Data analysis

Given the heterogeneity in study designs, a narrative synthesis was chosen over meta-analysis to map the research concepts and subgroup the findings based on different sub-questions, reflecting a consensus reached through active discussions among all authors. Such scoping reviews aim to extensively explore the concepts related to a particular research question. All authors were actively involved in discussions, reaching an agreement on how the results should be reported, which entailed subdividing them according to distinct sub-questions.

Results

Reliability

Figure 1 shows the study search, selection and inclusion process. Table 1 presents an overview of 24 studies categorized into five distinct health-related topics. The topics and the number of studies in each are as follows: Balance and risk of fall (7 studies), Emotional and mental health (6 studies), Metabolic parameters (4 studies), Cognitive functions (4 studies), and Quality of life (3 studies). Notably, two studies appear under multiple topics - the study by Park et al. (2023) is included in both the Emotional and mental health and the study Carrasco-Poyatos (2019) is listed under both Balance and risk of fall and Cognitive functions.

Balance and risk fall

Seven studies were found that included balance and risk of fall in older adult women and looked at the effects of Pilates on these variables. Pilates seems to be a good option for older adult women who have the fear of falling, who are looking to improve their balance and reduce the risk of falls. Małgorzata Długosz-Boś et al. showed that three months Pilates training in women aged over 60 years significantly improved Limits of Stability (LoS) test and the Modified Clinical Test of Sensory Interaction on Balance, whereby they showed that Pilates training affected the participants' balance and reducing fall risk (Długosz-Boś et al., 2021).

Table 1. Overview of included studies.

Topic	Author	Year	Duration	Comparison group	Variables	Outcome
Balance and risk fall	Długosz-Boś	2021	3 months	Only control	Balance (One Leg Stance Test, Freestep baropodometric platform, Modified Clinical Test of Sensory Interaction on Balance) fall risk (TUG, limits of stability test)	Significantly improved stability and Balance
	Cruz-Díaz	2015	6 weeks	Control was group with physical therapy alone	Fear of falling (Falls Efficacy Scale-international); functional mobility and balance (TUG, limits of stability test)	Significantly improved fear of falling and functional balance
	Kloubec	2010	12 weeks	Only control	Abdominal and upper body muscle endurance, hamstring flexibility, posture, and balance	Improved abdominal and upper body muscle endurance, hamstring flexibility, posture, and balance
	Hyun	2014	12 weeks	Unstable support surface exercise group	Balance (biofeedback analysis system, TUG, Romberg's test)	Significant improvements in the static and dynamic balance
	Markovic	2015	8 weeks	Huber group (feedback-based balance and core resistance training utilizing a special computer-controlled device)	Single- and dual-task static balance	Feedback-based balance and core resistance training is more effective than Pilates in single- and dual-task balance ability
	Carrasco-Poyatos	2019	18 weeks	Muscular and Control Group	trunk and hip isometric and hip isokinetic muscular flexion and extension strength (Isokinetic Dynamometer) One leg static balance (portable force platform)	Pilates more effective than muscular training program on trunk and hip isokinetic strength
Emotional and mental health	Ravari	2021	8 weeks	Only control	Depression (Oxford Happiness Inventory and Beck Depression Inventory)	Significantly increased happiness levels and lowered depression scores
	Aibar-Almazán	2019	12 weeks	Only control	Sleep quality (Pittsburgh Sleep Quality Index) fatigue (Fatigue Severity Scale)	Significant improvements in sleep, lower depression, anxiety and self-perceived fatigue

					anxiety, depression (Hospital Anxiety and Depression Scale)	
	Curi	2018	16 weeks	Only control	General health and sleep (Pittsburgh Sleep Quality Index and General Health Questionnaire)	Significant improvements on the life satisfaction scale's score
	Mohamed	2023	8 weeks	Only control	Fatigue (fatigue assessment scale and interleukin-6 test)	Significant decrease in fatigue and IL-6 production
	Soori	2021	12 weeks	Aerobic and control	Mental health (Goldberg General Health Questionnaire)	Significant decrease in depression score
	Park	2023	12 weeks	Online Pilates group (OPG), and a control group (CG)	Body composition (stadiometer and dual-energy X-ray absorptiometry) Mechanical muscle properties (contact soft tissue measuring device) Mental health (State-Trait Anxiety Inventory, autonomic nervous system activity and heart rate variability) Cardiometabolic parameters (resting blood pressure, blood lipid concentrations, blood glucose)	Pilates significantly improved mental health parameters with Face-to-face workout being more effective
Metabolic parameters	Marinda	2013	8 weeks	Only control	Cardiometabolic parameters	Significant decrease in systolic blood pressure
	Su	2022	12 weeks	Only control	Body composition (multiple bioelectric impendent analysis) Basal metabolic rate (Indirect calorimetric assessment) Cardiovascular capacity (three-minute step test and a higher-stress test than the six-minute walk test) Core muscle strength (1 min bent-knee sit-up test) Muscular Strength of Upper/Lower Limbs (grip strength meter) flexibility (sit-and-reach test)	Significantly improved body composition, including body mass index, body fat, basal metabolic rate, functional fitness, including flexibility, core strength, lower-limb strength, agility and balance.

	Park	2023	12 weeks	Online Pilates group, and a control group	Agility and Static/Dynamic Balance (8-foot timed up-and-go test) mental health (State-Trait Anxiety Inventory, autonomic nervous system activity and heart rate variability) cardiometabolic parameters (resting blood pressure, blood lipid concentrations, blood glucose)	Pilates significantly improved mental health parameters with Face-to-face workout being more effective, no effect on cardiometabolic parameters
	Kim	2014	Single session	No control, pre and post workout	Calcium metabolic markers and mRna expression of bone metabolic cytokines	Improvement in bone metabolic state
Cognitive functions	García-Garro	2020	12 weeks	Only control	Global cognitive function (Mini-Mental State Examination) Verbal Fluency (Isaacs test) Executive Function (Trail Making Test)	Improvements in verbal fluency and executive function
	Carrasco-Poyatos	2019	18 weeks	Muscular group and control group	Cognitive function (Mini-Mental State Examination) Static balance (force platform) Functional autonomy (GDLAM protocol)	Improvement in cognitive function and static balance
	Fontel da Silva	2022	12 weeks	Only control	Cognitive functions (Word List Memory test and Phonological Verbal Fluency test) Lower-limb strength (30-s Chair Stand Test) Balance (mini Balance Evaluation Systems Test) Functional mobility (TUG with and without dual-task)	Improvement in verbal fluency, immediate memory evocation memory, lower-limb muscle strength and balance

	Greblo Jurakic	2017	8 weeks	Control is combined balance and core resistance training group	Cognitive functions (Montreal Cognitive Assessment Test)	Significant improvements in global and specific cognitive domains.
Quality of life	Gandolfi	2019	20 weeks	Only control	Quality of life (SF-36 questionary) Markers of bone remodeling (blood laboratory testing) -	Improved quality of life No changes were noted in bone remodeling markers
	Küçükçakır	2013	12 months	Home and Pilates exercise groups	Pain (Visual Analog Scale) Functional status (six-minute walk test and sit-to-stand test) Quality of life (SF-36 questionary)	Improvement in pain, functional status and quality of life
	Angın	2015	6 weeks	Only control	Bone mineral density (densiometer) Pain (Visual Analog Scale) physical performance (6-minute walking test) quality of life (QUALEFFO-41 survey)	Increased bone mineral density, significant increases in physical performance, significantly decreased pain, significant increases in all parameters of quality of life

TUG - Timed Up and Go Test; PSQI-BR - Pittsburgh Sleep Quality Index – Brazil; GHQ-12 - General Health Questionnaire - 12 items; IL-6 - Interleukin-6; BSAP - Bone-Specific Alkaline Phosphatase

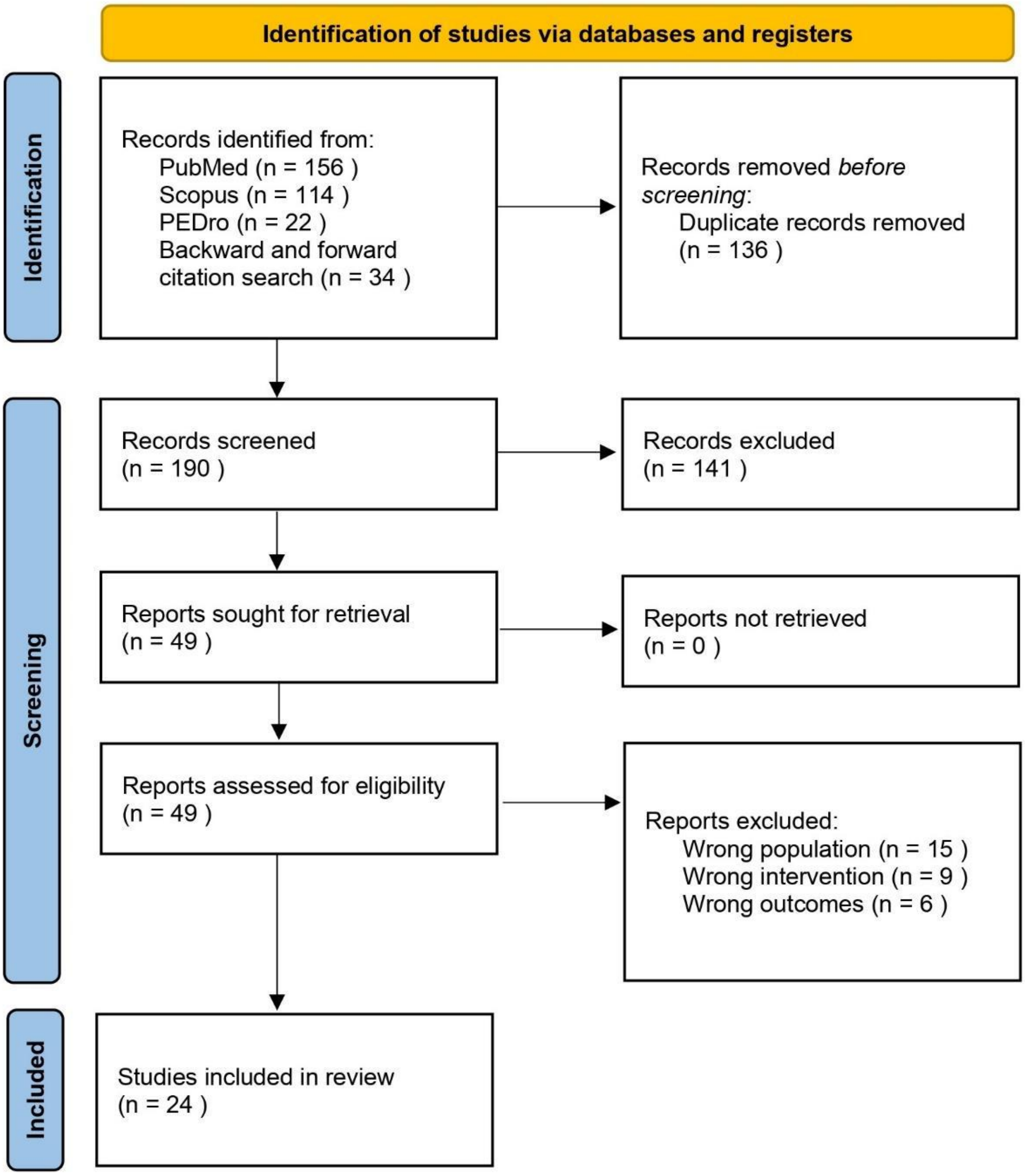

Figure 1. PRISMA study flowchart

Similar results were also shown by David Cruz-Díaz 2015 where six weeks of Pilates exercises were effective in fall prevention through the improvement of functional balance in Spanish women over 65 years old (David Cruz-Díaz et al., 2015). Kloubec et al. showed that in 12 weeks of Pilates exercise women were able to improve abdominal endurance, hamstring flexibility, upper-body muscular endurance, posture, and balance (Kloubec et al., 2010). Also, Hyun et al. showed significant effects on the static and dynamic balance of older adult female in a 12-week pilates program, (Hyun et al., 2014).

In comparison to other modalities Pilates showed mixed results. In 2015 Markovic et al showed that feedback-based balance and core resistance training is more effective then Pilates in single- and dual-task balance ability (Markovic et al., 5), however Carrasco-Poyatos et al. found Pilates more effective then muscular training program on trunk and hip isokinetic strength (Carrasco-Poyatos et al., 2019). De Andrade Mesquita et al. compared proprioceptive neuromuscular facilitation group and Pilates training. They showed significant improvement in static and dynamic balance in both test groups compared to control group (de Andrade Mesquita et al., 2015).

In summary, studies mostly showed an improvement of balance and reduced risk of fall in older adult women by addressing core strength, stability, and coordination. Pilates also helps to strengthen the muscles that play a key role in balance. This can lead to a greater sense of body awareness and control, ultimately enhancing balance both in daily activities and sports performance. Regular practice of Pilates can also help to prevent falls, particularly in older adults, by improving stability and reducing the risk of injury.

Emotional and mental health

Emotional and mental well-being is a big part of keeping a good quality of life in older adult women. As hormones lower in postmenopausal women and as family structure changes and retirement takes place, this can add significant weight on emotional and mental well-being in later years of women. Six interventional studies were identified where Pilates was evaluated also for emotional and mental health. Pilates presents an option where women can actively increase their happiness levels and decrease depression scores, as was shown in a study with married housewives age above 62 years. In this study participants already at he end of months one and two in the intervention groups increased significantly happiness levels and lowered depression scores, compared to those of the control group (Ravari et al., 2021). In postmenopausal women aged 60 and over significant improvements were observed after 12-week Pilates training in sleep, depression anxiety and also experienced a significant decrease in self-perceived fatigue after the intervention period (Aibar-Almazán et al., 2019). Another study revealed significant improvements on the life satisfaction scale's score for the group taking 16 weeks pilates training when compared to the control, suggesting a strong contribution of Pilates to healthy aging (Curi et.at., 2018). Fatigue is also an important factor contributing to quality of life in postmenopausal, Pilates intervention for 8 weeks showed a significant decrease in fatigue and also IL-6 production (Mohamed et al., 2023).

Soori et al. compared inactive older adult women divided into 3 groups: aerobic, Pilates and control group and followed for 12 weeks. (63.80 ± 3.35 years). The results indicate that Pilates exercises are more valuable than aerobic training in depression, however in other mental health components, the difference between the two exercise groups was not statistically significant, both improved mental health (Soori et al., 2022). Park et al., compared the effectiveness of online Pilates and face-to-face Pilates and found that both showed improvements of muscle mechanical properties, cardiometabolic parameters, mental health, and physical fitness. The results indicate that face-to-face Pilates is a more effective modality than online Pilates, although both modalities improve health-related parameters (Park et al., 2023).

In summary, the mind-body connection in Pilates encourages relaxation, and self-awareness, ultimately promoting a sense of calm and mental clarity, it seems that incorporating Pilates into a wellness routine in older adult women can help them feel more balanced and mentally resilient.

Metabolic parameters

Our search identified four studies looking at the effects of Pilates on diverse metabolic parameters in older adult women. As cardiovascular events are still the leading cause of mortality in older adult population, it is of vital importance to find ways to positively impact cardiovascular parameters.

One study aimed to determine the effects of mat Pilates on resting heart rate, resting blood pressure and fasting blood glucose, cholesterol and triglycerides in older adult women. In the eight-week mat Pilates progressive program the study demonstrated a significant decrease in systolic blood pressure, but not in other observed parameters (Marinda et al., 2013). Su et al. found that after the 12-week Pilates intervention, body composition, including body mass index, body fat amount, basal metabolic rate, functional fitness, including flexibility, core strength, lower-limb strength, agility and balance improved significantly in the experimental group relative to the control group (Su et al., 2022). Another study compared the effects of a face-to-face Pilates group and an online Pilates group with control group. Body composition, mechanical muscle properties, cardiometabolic parameters, mental health, and physical fitness were assessed before and after 12 weeks of intervention. Both exercise group showed improvements in terms of muscle mechanical properties, cardiometabolic parameters and physical fitness, where face-to-face workout was found to be more effective (Park et al., 2023). Kim at al. examined the effect of a single bout Pilates exercise on bone metabolism in older women with osteopenia. These results showed that a single bout Pilates exercise caused hypophosphatemia leading high turnover bone metabolic state. Suggesting positive effects on both bone formation and bone resorption (Kim et al., 2014).

In summary, studies showed positive effects on blood pressure, but not all metabolic parameters, and one study points to possible effects in bone metabolism.

Cognitive functions

Cognitive changes are a normal part of aging, but it is vital to healthy aging to keep the gradual decline of cognitive functions such as vocabulary, conceptual reasoning, memory, and processing speed as slow as possible. Four studies were found that examined the effects of Pilates on cognitive function in postmenopausal women.

García-Garro et al. found that women in the Pilates group experienced improvements in verbal fluency and executive function but not in global cognitive function among Spanish women aged 60 years and over (García-Garro et al., 2020). One study compared the effects of 18-week Pilates and muscular exercise intervention on cognitive function and found improvements in both groups compared to control, with plates having a better general functional condition index than the group with muscular excersizes (Carrasco-Poyatos et a., 2019). In one study they combined Pilates with cognitive tasks in a 12-week intervention and assessed cognitive performance. The intervention group showed significant improvement in verbal fluency, immediate memory and evocation memory (da Silva et al., 2022). Greblo Jurakic et al. studied the effect of exercise on women that already showed the signs of mild cognitive impairment, the participants were assigned to either a combined balance and core resistance training group or to a Pilates group. After 8-week exercise programme, both groups showed significant improvements in global and specific cognitive domains (Greblo Jurakic et al., 2017).

In summary, incorporating Pilates for postmenopausal women as part of their routine, was shown to have beneficial effects of age-related cognitive decline leading to improvements in all aspects of cognitive performance.

Quality of life

For older adult women many factors contribute to quality of life. For most it is vital to be able to do daily activities, manage pain and maintain social activities as a part of healthy aging. Pilates seems to be a very effective measure to improve pain, engage socially and generally improve quality of life.

We identified four research papers that examined the effects of Pilates on quality of life in this population. A study of 40 women aged over 60 years showed that 20-week Pilates program, improved quality of life but did not show changes in bone remodeling compared to control group (Gandolfi ez al., 2020). Küçükçakır et al. valuated the effects of Pilates exercise program on pain, functional status and quality of life in women with postmenopausal with existing osteoporosis. The study compared the effects of supervised Pilates exercise program with home exercise group. After one-year significant improvement was noted in all evaluation parameters, with significantly greater improvement in the Pilates exercise group compared to the home exercise group (Küçükçakır et al., 2013). Pilates exercises was an effective intervention to improve the quality of life and also to relieve pain and increase bone mineral density in postmenopausal women with osteoporosis as was shown by Angın et al. in 2015. Women in control group had an expected decline in bone mineral density, increased pain and lower quality of life (Angın et al., 2015). One study looked at the effects of pilates on the quality of life of sedentary older adult women. Over six months the women in performed Pilates and the control group did not. The intervention group achieved significant improvements in functional capacity, physical aspects, pain, general health condition, vitality, social aspects and mental health, all contributing significantly to an improvement in quality of life.

In summary, study results show that implementation of a Pilates program can improve quality of life in older adult women, where we can also see improvements in pain management and bone densit

Discussion

Limitations

This scoping review, while offering a comprehensive overview of the impact of Pilates quality of life in older adult women, has several limitations. Its scoping review nature precludes deeper analytical insights and causal determinations compared to systematic reviews or meta-analyses; thus, the conclusions are indicative rather than conclusive. This scoping review is designed to map the breadth and nature of the available evidence, rather than to synthesize quantitative outcomes or critically appraise the methodological quality of the included studies. The included studies exhibit methodological heterogeneity and variability in Pilates protocols, challenging the generalizability of findings and synthesis of evidence. Additionally, the literature search may have missed pertinent studies due to language and publication biases, limiting the scope of analyzed data. The focus on older adult women, excluding other demographics, narrows the applicability of our findings. Therefore, interpretations of this scoping review should be cautious, especially in terms of extrapolation of the findings to other populations.

Clinical application

This scoping review highlights Pilates as an effective intervention for enhancing the health and quality of life in older adult women, suggesting the possibility of Pilates integration into geriatric healthcare strategies. Clinicians should tailor Pilates programs to individual patient profiles, emphasizing core strength, balance, and flexibility to mitigate fall risk and improve mental well-being. Collaboration with certified Pilates instructors experienced in geriatric exercise can ensure safe, effective implementation. Further, incorporating Pilates within multimodal interventions may provide even larger health outcomes than Pilates-only interventions. In sum, Pilates presents a significant opportunity for healthcare professionals to enhance the quality of life in older adult women through individually-tailored and low-impact physical activity. Pilates can be performed as a floor based exercise and is also safe for older women with disabilities.

Conclusion

This scoping review provides evidence synthesis on the beneficial impacts of Pilates on the health and quality of life of older adult women, demonstrating its potential as an exercise modality for this demographic. By highlighting improvements in physical capacities, mental well-being, and overall quality of life, this scoping review supports the inclusion of Pilates in comprehensive care strategies for aging populations. Future research should aim expand this evidence, ensuring Pilates is optimally utilized in geriatric healthcare to promote healthy aging and enhanced life quality among older adult women.

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References

Aunola, S. & Rusko, H. (1986). Aerobic and anaerobic thresholds determined from venous lactate and from ventilation and gas exchange in relation to muscle fiber composition. *International Journal* of *Sports Medicine*, 7, 161-166.

Beneke, R. (1995). Anaerobic threshold, individual anaerobic threshold and maximal lactate steady state in rowing. *Medicine* & *Science* in *Sports* & *Exercise,* 27, 86-87.

Billat, V., Dalmay, F., Antonini, M.T. & Chassain, A.P. (1994). A method for determining the maximal steady state of blood lactate concentration from two levels of submaximal exercise. *European Journal of Applied Physiology*, 69, 196-202.

Bishop, D., Jenkins, D.G. & Mackinnon, L.T. (1998) The relationship between plasma lactate parameters, Wpeak and 1-h cycling performance in woman. *Medicine* & *Science* in *Sports* & *Exercise,* 30(8), 1270-1275.

Boulay, M.R., Hamen, P., Simoneau, J.A. et al. (1984). A test of anaerobic capacity: description and reliability. *Canadian Journal of Applied Sport Sciences*, 9, 122-126.

Bourgois, J, & Vrijens J. (1998). The Conconi test: a controversial concept for the determination of the anaerobic threshold in young rowers. *International Journal* of *Sports Medicine,*19, 553-559.

Brooks, G.A. (1985). Anaerobic threshold: review of the concept and direction of future research. *Medicine* & *Science* in *Sports* & *Exercise*, 17, 22-31.

Buchfuhrer, M.J., Hansen, J.H., Robinson, T.E., Sue, D.Y., Wasserman, K. &Whipp, B.J. (1983). Optimizing the exercise protocol for cardiopulmonary assessment. *Journal of Applied Physiology*, 55, 558-564.

Burke J, Thayer, R. & Belcamino, M. (1994). Comparison of effects of two interval-training programmes on lactate and ventilatory thresholds. *British Journal of Sports Medicine*, 28, 18-21.

Carter, H., Jones, A.M. & Doust, J.H. (1999). Effect of 6 weeks of endurance training on the lactate minimum speed. *Journal of* Sports *Sciences*, 17, 957-967.

Cellini, M., Vitiello, P., Nagliati, A., Ziglio, P.G… Concioni, F. (1986). Non-invasive determination of the anaerobic threshold in swimming. *International Journal* of *Sports Medicine,* 7, 347-351.

Cheng, B., Kuipers, H., Snyder, A.C., Keizer, H.A., Jeukendrup, A. & Hesselink, M. (1992). A new approach for the determination of ventilatory and lactate tresholds. *International Journal of* Sports *Medicine,* 13(7), 518-522.

Conconi, F., Ferrari, M., Zigilo, P.D., Droghetti, P. & Codeca, L. (1982). Determination of the anaerobic threshold by a non-invasive field test in runners. *Journal of Applied Physiology*, 52, 34-43.

Conconi, F., Grazzi, G., Casoni, I., Gulielmini, C., Borsetto, C… Manfredini, F. (1996). The Conconi test: methodology after 12 years of application. *International Journal* of *Sports Medicine,* 17, 509-519.

Connett, R. J., Gayeski, T.E. & Honing, C.R. (1984). Lactate accumulation in fully aerobic, working dog gracillis muscle. *American Physiological Society*, 24, 120-128.

Davis, H.A. & Gass, G.C. (1979). Blood lactate concentration during incremental work before and after maximum exercise. *British Journal of Sports Medicine*, 13, 165-169.

Davis, J.A., Vodak, P., Wilmore, J.H., Vodak, J. & Kurtz, P. (1976). Anaerobic threshold and maximal aerobic power for three modes of exercise. *Journal of Applied Physiology,* 41, 544-550.

Dekerle, J., Baron, B., Dupont, L., Vanvelcenaher, J. & Pelayo, P. (2003). Maximal lactate steady state, respiratory compensation threshold and critical power. *European Journal of Applied Physiology*, 89, 281-288.

Droghetti, P., Borsetto, C., Casoni, I., Cellini, M., Ferrari, M., Paolini, A.R., Zigilio, P.G. & Conconi, F. (1985). Non-invasive determination of the anaerobic threshold in canoeing, cross-country skiing, cycling, roller and ice skating, rowing and walking. *European Journal of Applied Physiology,* 53, 299-303.

Gladden, L.B., Yates, W., Stremel, R.W. & Stamford, B.A. (1985). Gas exchange and lactate anaerobic thresholds: inter- and intraevaluator agreement. *Journal of Applied Physiology,* 58(6), 2082-2089.

Heck, H., Mader, A., Hess, G., Mucke, S., Muller, R. & Hollmann, W. (1985). Justification of the 4 mmol/l lactate threshold. *International Journal of* Sports *Medicine* 6(3), 117-130.

Hermansen, L. & Stenvold, I. (1972). Production and removal of lactate during exercise in man. *Acta Physiologica Scandinavica*, 89, 191-201.

Holmann, W, Rost, R., Liesen, H., Dufaux, B., Hecke, H. & Mader, A. (1981). Assessment of different forms of physical activity. *International Journal of* Sports *Medicine*, 2(2), 67-80.

Hughson, R.L., Weisiger K.H. & Swanson G.D. (1987). Blood lactate concentration increases as a continuous function in progressive exercise. *Journal of Applied Physiology,* 62(5), 1975-1981.

Hugues, E.F., Turner, S.C. & Brooks, G.A. (1982). Effects of glycogen depletion and pedaling speed on anaerobic threshold. *Journal of Applied Physiology,* 52(6), 1598-1605.

Hurley, B.F. (1984). Effect of training on blood lactate level during submaximal exercise. *Journal of Applied Physiology,* 56(5), 1260-1264.

Ivy, J.L., Withers, R.T., Van Handel, P.J., Elger, D.H. & Costill D.L. (1980). Muscle respiratory capacity and fiber type as determinants of the lactate threshold. *Journal of Applied Physiology: respiratory, environmental and exercise physiology*, 48, 523-527.

Jeukendrup, A.E., Hesselink, M.K.C., Kuipers, H. & Keizer, H.A. (1997). The Conconi test. *International Journal* of *Sports Medicine,* 18:393-394.

Jones, A.M. & Doust, J.H. (1997). The Conconi test is not valid for estimation of the lactate turn point in runners. *Journal of* Sports *Sciences*, 15, 385-394.

Kang, J., Chaloupka, E.C., Mastrangelo, M.A., Biren, G.B. & Robertson, R.J. (2001). Physiological comparisons among three maximal treadmill exercise protocols in trained and untrained individuals. *European Journal of Applied Physiology,* 84(4), 291-295.

Kayser, B. (1996). Lactate during exercise at high altitude. *European Journal of Applied Physiology*, 74, 195-205.

Keul, J., Simon, G., Berg, A., Dickhuth, H.H. Goerttler, i & Kuebel, R. (1979). Bestimmung der individuellen anaeroben schwelle zur leistungsbewertung und trainingsgestaltung [Determination of the individual anaerobic threshold for performance assessment and training design]. *Deutsche Zeitschrift fur Sportmedizin, 30*(7), 212-218.

LaFontaine, T.P., Londeree, B.R. & Spath, W.K. (1981). The maximal steady state *vs* selected running events. *Medicine* & *Science* in *Sports* & *Exercise,* 13(3), 190-193.

Londeree, B. (1997). Effect of training on lactate/ventilatory thresholds: a meta-analysis. *Medicine* & *Science* in *Sports* & *Exercise,* 29(6), 837-843.

Moritani, T. & DeVries, H.A. (1997). Anaerobic threshold determination by surface electromyography. *Medicine* & *Science* in *Sports* & *Exercise*. 12, 86.

Noakes, T.D. (1997). Challenging beliefs: ex Africa semper aliquid novi. *Medicine* & *Science* in *Sports* & *Exercise,* 29, 571-590.

Oyono-Enguelle, S., Heitz, A., Marbach, J., Ott, C., Gartner, M., Pape, A., Vollmer, J.C. & Freund, H. (1990). Blood lactate during constant load exercises at aerobic and anaerobic thresholds. *European Journal of Applied Physiology*, 60(5), 321-330.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery,* vol. 88, 1-9.

Page, M.J., McKenzie, J.E., Bossuyt, P-M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ Research Methods & Reporting*, 372: n71.

Palgi, Y., Gutin, B., Young, J. & Alejandro, D. (1984). Physiologic and anthropometric factors underlying endurance performance in children. *International Journal* of *Sports Medicine,* 5(2), 67-73.

Palka, M.J. & Rogozinski, A. (1986). Standards and predicted values of anaerobic threshold. *European Journal of Applied Physiology*, 54, 643-646.

Péronnet, F., Thibault, G., Rhodes, E.C. & McKenzie, D.C. (1987). Correlation between ventilatory threshold and endurance capability in marathon runners. *Medicine* & *Science* in *Sports* & *Exercise,* 19(6), 610-615.

Petit, M.A., Nelson, C.M. & Rhodes, E.C. (1997). Comparison of a mathematical model to predict 10 km performance from the Conconi test and ventilatory thresholds measurements. *Canadian Journal of Applied Physiology,* 22(6), 562-72.

Pokan, R., Hofmann, P., Lehmann, M., Leitner, H., Eber, B., gasser, R., Schwaberger, G., Schmid, P., Keul, j. & Klein, W. (1995). Heart rate deflection related to lactate performance curve and plasma catecholamine response during incremental cycle ergometer exercise. *European Journal of Applied Physiology,* 70(2), 175-179.

Ribeiro, J.P., Hughes, V., Fielding, R.A., Holden, W., Evans, W. & Knuttgen, H.G. (1986). Metabolic and ventilatory response to steady state exercise relative to lactate thresholds. *European Journal of Applied Physiology*, 55(2), 215-221.

Scheen, A., Juchmes, J. & Cession-Fossion, A. (1981). Critical analysis of the "Anaerobic threshold" during exercise at constant workloads. *European Journal of Applied Physiology*, 46(4), 367-377.

Simon, G., Berg, A., Dickhuth, H.H., Simon-Alt, A. & Keull, J. (1981). Bestimmung der anaeroben hwelle in abhangigkeit vom alter und von der leistungshigkeit [Determination of the anaerobic threshold depending on age and performance level]. *Deutsche Zeitschrift fur Sportmedizin, 32*(1), 7-14.

Sjödin, B. & Jacobs, I. (1981). Onset of blood lactate accumulation and marathon running performance. *International Journal* of *Sports Medicine,* 2, 123-135.

Skinner, J.S. & McLellan, T.H. (1980). The transition from aerobic to anaerobic metabolism. *Research Quarterly for Exercise and Sport,* 5(1), 234-248.

Snyder, A.C., Woulfe, T., Welsh, R. & Foster, C. (1994). A simplified approach to estimating the maximal lactate steady state *International Journal* of *Sports Medicine*, 15(1), 27-31.

Stegmann, H., Kindermann W. & Schabel, A. (1981). Lactate kinetics and individual anaerobic threshold. *International Journal* of *Sports Medicine,* 2(3), 160-165.

Sucec, A.A., Ponton, L.J., Tucker, S. & Macy, R. (1985). Validity of gas exchange indices as a measure of anaerobic threshold on the treadmill. In: Dotson C.O., Humphrey, J.H., editors. *Exercise physiology: current selected research,* 2, 31-43.

The EndNote Team. EndNote. EndNote X9 ed. Philad, PA: Clarivate; 2013. http://www.endnote.com.

Thorland, W., Podolin, D.A. & Mazzeo, R.S. (1984). Coincidence of lactate threshold and HR-power output threshold under varied nutritional states. *International Journal* of *Sports Medicine,* 15(6), 301-304.

Tokmakidis, S.P. (1990). *Anaerobic threshold in perspective: physiological, methodological and practical implications of the concept* [PhD thesis]. Montréal: Université de Montréal.

Tokmakidis, S.P., Leger, L.A. & Pilianidis, T.C. (1998). Failure to obtain a unique threshold on the blood lactate concentration curve during exercise. *European Journal of Applied Physiology*, 77(4), 333-342.

Urhausen, A., Coen, B., Weiler, B. & Kindermann W. (1993) Individual anaerobic threshold and maximal lactate steady state. *International Journal* of *Sports Medicine*, 14(3), 134-139.

Walker, J. & Eisenman, P. (1995). Validity of heart rate inflection point or a 3.2-kilometer performance pace as estimators of maximal steady state running velocity in high school runners. *Sports Medicine*, *Training* and *Rehabilitation*, 6, 215-222.

Wasserman, K., & McIlroy, M. B. (1964). Detecting the threshold of anaerobic metabolism in cardiac patients during exercise. *American Journal of Cardiology*, 14, 844-852.

Wasserman, K., Beaver, W.L., Davis, J.A., Pu, J.Z., Heber, D. & Whipp, B.J. (1985). Lactate, pyruvate, and lactate to pyruvate ratio during exercise and recovery. *Journal* of *Applied Physiology*. 59(3), 935-940.

Wasserman, K., Whipp, B.J., Koyl, S.N. & Beaver, W.L. (1973). Anaerobic threshold and respiratory gas exchange during exercise. *Journal* of *Applied Physiology,* 35(2), 236-243.

Whipp, B.J., Davis, J.A., Torres, F. & Wasserman, K. (1981). A test to determine the parameters of aerobic function during exercise. *Journal of Applied Physiology,* 50(1), 217-221.

Williams, J.R. & Armstrong, N. (1991). The influence of age and sexual maturation on children's blood lactate response to exercise. *Pediatric Exercise Science,* 3, 111-120.

Worms, F., Kozariszcuk, G., & Hunger, K. L. (1985). Untersuchungen zur Herzschlagfrequenz im aerob-anaeroben Übergang bei der Fahrradergometrie im mittleren und hohen Lebensalter. [Investigations into heart rate in the aerobic-anaerobic transition during bicycle ergometry in middle and old age]. *Medizin und Sport*, 25, 85-91.

Wyndham, C.H., Strydom, N.B., Maroitz, J.S., Morrison, J.F., Peter, J. & Potigieter, Z.U. (1959). Maximum oxygen intake and maximum heart rate during strenuous work. *Journal* of *Applied Physiology,* 14, 927-936.

Yeh, M.P., Gardner, R.M., Adams, T.D., Yanowitz, F.G. & Crapo, R.O. (1983). Anaerobic threshold, problems of determination and validation. *Journal* of *Applied Physiology,* .55(4), 1178-1186.

Yoshida, T., Nagata, A., Muro, M., Takeuchi, N. & Suda, Y. (1981). The validity of the anaerobic threshold determination by Douglas bag method coupled with arterial blood lactate concentration. *European Journal of Applied Physiology* and *Occupational Physiology*, 46(4), 423-430.