

# Exercise Interventions for Musculoskeletal and Mental Health: A Systematic Review of Randomized Controlled Trials

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## Abstract

**Background:** Exercise interventions are increasingly recognized as important strategies for improving musculoskeletal and mental health outcomes. Various forms of exercise, including resistance training, mind-body practices, and digitally delivered exercise programs, have been investigated in recent years; however, the overall evidence from randomized controlled trials (RCTs) remains fragmented.

**Objectives:** To examine the effects of resistance, mind-body, and digitally delivered exercise interventions on musculoskeletal and mental health outcomes.

**Methods:** A systematic review of RCTs was conducted following established methodological guidelines. RCTs published between January 2020 and December 2023 were identified using PubMed, Scopus, Web of Science, and ScienceDirect databases. Eligible studies evaluated structured exercise interventions targeting musculoskeletal or mental health outcomes. Data extraction was performed systematically. Methodological quality and risk of bias were assessed using the Risk of Bias Tool developed by the Cochrane Collaboration, covering domains including random sequence generation, allocation concealment, blinding, incomplete outcome data, and selective reporting. A narrative synthesis was undertaken to summarize the findings and provide a comprehensive overview of the results across the studies included in the review due to substantial heterogeneity in interventions, populations, and outcome measures.

**Results:** The included studies demonstrated that exercise interventions were associated with improvements in several outcomes, including reductions in musculoskeletal pain and occupational fatigue, improvements in sleep quality and psychological well-being, and enhanced physical function among older and prefrail individuals. Resistance training and mind-body exercise showed consistent benefits, while technology-assisted and digitally delivered exercise programs also demonstrated promising results. However, methodological heterogeneity, the varying risk of bias, and relatively short follow-up periods across studies limit the strength of the conclusions.

**Conclusions:** Exercise interventions improve musculoskeletal and mental health outcomes; however, more high-quality RCTs with standardized measures and long-term follow-up are needed to strengthen evidence and implementation.

**Keywords:** Exercise interventions, Musculoskeletal health, Mental health, Randomized controlled trials

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## Introduction

Musculoskeletal disorders and mental health conditions are major contributors to the global burden of disease and disability. Musculoskeletal problems such as chronic pain, fatigue, and functional limitations, affect millions of people worldwide and are among the leading causes of years lived with disability.<sup>1</sup> These conditions often reduce work productivity, physical functioning, and overall quality of life. At the same time, mental health problems including stress, anxiety, depression, and sleep disturbances, are increasingly prevalent and frequently coexist with musculoskeletal disorders, creating complex interactions between physical and psychological health.<sup>2, 3</sup> The coexistence of these conditions highlights the need for comprehensive interventions that address both musculoskeletal and mental health outcomes.

In recent years, this question has gained urgency due to converging developments. First, the global rise in musculoskeletal disorders, mental health conditions, and population aging has increased the demand for targeted and scalable exercise interventions. Occupational fatigue, work-related musculoskeletal pain, frailty, sleep disturbances, and stress-related disorders are increasingly prevalent among workers and older adults. Evidence from randomized controlled trials (RCTs) indicates that structured resistance and multicomponent exercise programs can reduce fatigue and pain in occupational settings and improve physical function among older populations.<sup>4</sup> Second, the COVID-19 pandemic fundamentally disrupted conventional face-to-face exercise delivery, contributing to widespread reductions in physical activity and heightened risks of mental distress, particularly among older adults. During this period, online and remotely delivered exercise programs emerged as critical alternatives for maintaining physical activity and psychological well-being.<sup>5</sup> Third, and most notably, recent years have seen rapid growth in technology-assisted and artificial intelligence (AI) — supported exercise interventions, representing a qualitative shift from traditional exercise prescriptions toward personalized, adaptive, and data-driven approaches. AI-assisted programs integrating digital feedback and monitoring have demonstrated effectiveness in reducing neck, shoulder, and low back pain among office workers, suggesting potential advantages in adherence and individualization compared with conventional programs.<sup>6</sup> These developments introduce a clear scientific and practical controversy: whether emerging digital and AI-assisted exercise modalities offer comparable or superior benefits relative to traditional resistance, aerobic, or mind-body interventions.

Mind-body exercise programs have also gained increasing attention, particularly in aging and postpandemic contexts. Interventions such as Baduanjin and mindfulness-based movement combine physical activity with cognitive and emotional regulation, potentially addressing both physical and mental health outcomes simultaneously. Randomized trials have shown that such interventions improve sleep quality, quality of life, and stress-related outcomes in older adults and mixed populations.<sup>7-9</sup> Neurobiological and psychological mechanisms, including endorphin release, stress modulation, and enhanced self-regulation, are thought to underpin these benefits.<sup>10</sup>

Although a growing number of studies have examined the benefits of exercise interventions, the available evidence remains fragmented. Many previous studies and reviews have focused on specific types of exercise or particular populations, such as individuals with chronic musculoskeletal conditions or older adults. In addition, emerging interventions such as digitally delivered or technology-assisted exercise programs have not been consistently synthesized alongside traditional exercise approaches in

previous systematic reviews. Consequently, there is limited comprehensive synthesis of evidence comparing different exercise modalities and their combined effects on both musculoskeletal and mental health outcomes.<sup>11</sup> Others concentrate on specific population groups, particularly older adults, without systematically comparing delivery formats or intervention mechanisms. Conversely, broader reviews often aggregate heterogeneous exercise programs without sufficient distinction between intervention type, delivery mode, and contextual drivers, limiting their applicability to real-world health promotion and occupational health settings. Health disparities related to access to exercise opportunities particularly between urban and rural populations — further complicate the interpretation of the evidence.<sup>12, 13</sup>

The period from 2020 onward represents a methodologically distinct phase in exercise research. RCTs conducted during and after the COVID-19 pandemic increasingly incorporated online delivery, remote supervision, and digital technologies, reflecting evolving health system realities.<sup>13</sup> However, no recent systematic review has explicitly synthesized RCT evidence from this period with a focus on both exercise modality (eg, resistance, mind-body, multi-domain) and delivery innovation (eg, AI-assisted, online platforms) across musculoskeletal and mental health outcomes.

Therefore, this systematic review aimed to synthesize evidence from RCTs examining the effects of resistance exercise, mind-body exercise, and digitally delivered exercise interventions on musculoskeletal and mental health outcomes. By integrating findings across diverse intervention types and populations, this review seeks to provide a clearer understanding of the role of exercise interventions in improving both physical and psychological health and to inform future health promotion strategies and clinical practice.

## Methods

### Search Strategy

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. A comprehensive literature search was performed to identify relevant RCTs evaluating the effects of exercise interventions on health promotion. Electronic searches were conducted in PubMed, Scopus, Web of Science, and ScienceDirect, covering studies published between January 2020 and December 2023. The final database search was completed on 15 January 2024. No additional records were identified after this date.

### Inclusion and Exclusion Criteria

This review applied predefined eligibility criteria to ensure the methodological rigor and relevance of the included studies. Only RCTs published between January 2020 and December 2023 were eligible for inclusion. Studies were required to evaluate exercise-based interventions specifically aimed at promoting health. Furthermore, only studies published in the English language with full-text availability were included.

Studies were excluded if they were not RCTs, if the full-text was unavailable, or if the article was published in a language other than English.

### Search Terms

The search terms used were a combination of keywords and Medical Subject Headings related to exercise and health promotion (Supplementary S1). The search terms

included: "exercise", "physical activity", "health promotion", "randomized controlled trial", "RCT", "intervention", "musculoskeletal health", and "mental health".

### Data Sources and Search Engines

The search was conducted across several databases, yielding a total of 155 articles. Specifically, 50 articles were retrieved from PubMed, 40 from Scopus, 35 from Web of Science, and 30 from ScienceDirect. The distribution of articles from each database was as follows: PubMed contributed 32%, Scopus 26%, Web of Science 23%, and ScienceDirect 19%.

### Screening and Study Selection

Study selection was conducted in accordance with the PRISMA 2020 statement. All records retrieved from the electronic database searches were imported into EndNote reference management software, and duplicate records were identified and removed prior to screening. Two reviewers (P.T. and N.T.) independently screened the titles and abstracts of all remaining records against the predefined inclusion and exclusion criteria. Articles deemed potentially eligible by either reviewer were retrieved in full-text for further assessment.

Full-text articles were then independently evaluated for eligibility by the same 2 reviewers. Disagreements at either the title/abstract screening stage or the full-text assessment stage were resolved through discussion and consensus. When consensus could not be reached, a third reviewer (R.K.) was consulted to make the final decision. This independent and duplicate screening process was implemented to minimize selection bias and to ensure transparency and reproducibility of the review process.

### Data Extraction

Data extraction was performed using a standardized data extraction form developed a priori. Two reviewers (T.N. and K.R.) independently extracted data from each included study. Extracted information included study characteristics (author, year, country, and study design), participant characteristics (population and sample size), and details of the exercise intervention (type, duration, and frequency), outcome measures related to physical and mental health, and key findings. Following independent data extraction, the extracted datasets were cross-checked for accuracy and completeness. Any discrepancies between reviewers were discussed and resolved by consensus. If disagreement persisted, a senior author (N.T.) reviewed the original study and made the final determination. This structured, duplicate data extraction process was adopted to reduce the risk of data extraction errors and reviewer bias.

A total of 155 articles were initially retrieved, with 35 duplicates removed. After screening titles and abstracts, 120 articles remained, of which 45 full-text articles were assessed for eligibility. Ultimately, 15 articles were included in the final review.

### Quality Assessment

The quality of the included studies was evaluated using the Cochrane Collaboration's tool for assessing the risk of bias in RCTs. This assessment involved several key domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other potential sources of bias. Each domain was rated as having a "low risk", "high risk", or "unclear risk" of bias. The detailed results of this assessment, including individual domain ratings for each study.

Data Synthesis

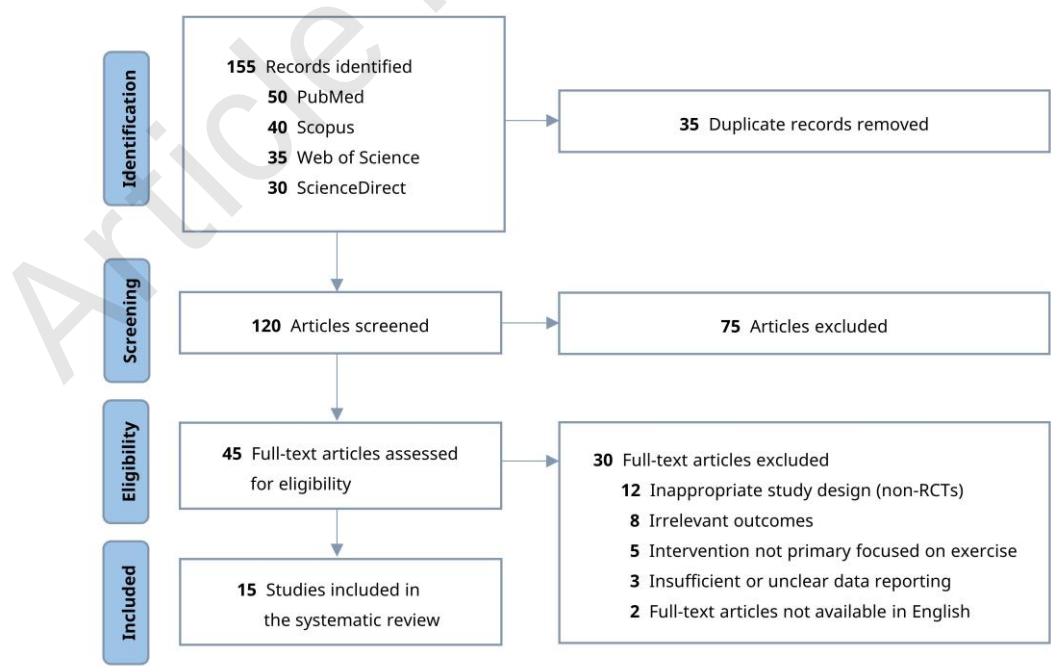
The quality of the included studies was evaluated using the Cochrane Collaboration's tool for assessing the risk of bias in randomized controlled trials. This assessment involved several key domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other potential sources of bias. Each domain was rated as having a "low risk", "high risk", or "unclear risk" of bias. The detailed results of this assessment, including individual domain ratings for each study.

Results

Study Selection

The initial literature search identified a total of 155 articles from 4 databases: PubMed (50 articles), Scopus (40 articles), Web of Science (35 articles), and ScienceDirect (30 articles). After removing 35 duplicates, 120 articles underwent screening based on their titles and abstracts, resulting in the exclusion of 75 articles that either did not meet the inclusion criteria or were not RCTs. The full texts of 45 articles were assessed for eligibility, and 30 studies were excluded due to inappropriate study design (n = 12), irrelevant outcomes (n = 8), interventions not primarily focused on exercise (n = 5), insufficient data reporting (n = 3), or non-English full text (n = 2). Ultimately, 15 RCTs were included in this systematic review. The study selection process is presented in the PRISMA flow diagram (Figure 1).

Figure 1. A PRISMA Flow Diagram of the Study Selection Process



Abbreviations: PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCTs, randomized controlled trials.

### Study Characteristics

The included studies evaluated various exercise interventions, including progressive resistance training, mind-body exercises, multi-domain exercise programs, and technology-assisted or online exercise interventions. The studies involved diverse populations, including industrial workers, office workers, community-dwelling older adults, and prefrail elderly individuals. The primary outcomes assessed across the studies included musculoskeletal pain, fatigue, sleep quality, psychological well-being, muscle strength, and physical function (Table 1).

### Risk of Bias Assessment

The methodological quality of the included trials was variable. Most studies reported a low risk of bias in random sequence generation and incomplete outcome data. However, allocation concealment and blinding of participants and personnel were frequently unclear or rated as high risk, reflecting both insufficient reporting and practical challenges in blinding exercise interventions. Blinding of outcome assessment was inconsistently reported, although selective reporting was generally judged to be at low risk (Table 2).

### Key Findings

#### *Fatigue Control and Pain Reduction*

The study by Santos et al<sup>2</sup> found that a progressive resistance exercise program significantly improved perceived fatigue control among industrial workers. Similarly, Anan et al<sup>6</sup> reported that an AI-assisted health program effectively reduced neck and shoulder pain, as well as low back pain, among office workers. These findings suggest that targeted exercise interventions can be beneficial in occupational settings to mitigate work-related fatigue and musculoskeletal pain.

#### *Health Disparities*

Vilpunaho et al<sup>12</sup> highlighted health disparities between urban and rural populations. Urban RCT participants, who had better access to exercise facilities and programs, were healthier compared with nonparticipants or rural women. This study underscores the importance of addressing environmental and accessibility factors when promoting health equity.

#### *Sleep Quality and Mental Health*

Several studies focused on the impact of exercise on sleep quality and mental health. Fan et al<sup>14</sup> demonstrated that mind-body exercises, such as Baduanjin, significantly improved sleep quality and quality of life in elderly individuals with sleep disturbances. Jurado-Fasoli et al<sup>8</sup> also reported improvements in sleep quality through regular exercise training. Additionally, Díaz-Silveira et al<sup>9</sup> compared mindfulness exercises with physical exercise and found both to be effective in reducing stress and enhancing mental health.

#### *Physical Fitness and Functional Improvements*

Lai et al<sup>3</sup> found that lower-limb resistance exercise improved muscle strength, physical fitness, and metabolism in prefrail elderly patients. Similarly, Murukesu et al<sup>4</sup> reported that a multidomain intervention protocol improved physical function and reduced frailty among elderly participants. These studies highlight the importance of tailored exercise programs in enhancing physical fitness and functional abilities in older adults.

### *Innovative and Online Interventions*

Beauchamp et al<sup>5</sup> explored the effectiveness of online-delivered group and personal exercise programs for older adults during the COVID-19 pandemic. The study found significant improvements in mental health, demonstrating the potential of digital platforms for promoting physical activity and well-being, especially in times of restricted physical interactions.

### *Summary of Findings*

Overall, the included studies indicate that resistance training, mind-body exercises, and digitally delivered exercise interventions are associated with improvements in musculoskeletal and mental health outcomes. Progressive resistance exercise and AI-assisted programs were particularly effective in reducing occupational fatigue and musculoskeletal pain, while mind-body practices contributed to better sleep quality and psychological well-being. Lower-limb resistance and multi-domain exercise programs also improved physical fitness and reduced frailty among older adults. Additionally, online and technology-assisted exercise interventions demonstrated potential for maintaining physical activity and support mental health during periods of restricted social interaction.

**Table 1. Characteristics of the Included Studies**

| Source                                 | Country  | No. of Participants | Population             | Intervention                     | Duration  | Outcomes                          | Key Findings                                         |
|----------------------------------------|----------|---------------------|------------------------|----------------------------------|-----------|-----------------------------------|------------------------------------------------------|
| Santos et al, <sup>2</sup> 2020        | Brazil   | 204                 | Industrial workers     | Progressive resistance exercise  | 12 weeks  | Fatigue control                   | Significant improvement in perceived fatigue control |
| Lai et al, <sup>3</sup> 2021           | China    | 60                  | Prefrail older adults  | Lower-limb resistance exercise   | 8 weeks   | Muscle strength, metabolism       | Improved strength and metabolic outcomes             |
| Murukesu et al, <sup>4</sup> 2020      | Malaysia | 122                 | Older adults           | Multidomain exercise program     | 12 months | Frailty, physical function        | Reduced frailty, improved function                   |
| Beauchamp et al, <sup>5</sup> 2021     | Canada   | 241                 | Older adults           | Online exercise programs         | 12 weeks  | Mental health                     | Improved mental health during COVID-19               |
| Anan et al, <sup>7</sup> 2021          | Japan    | 140                 | Office workers         | AI-assisted health program       | 8 weeks   | Neck/shoulder pain, low back pain | Reduced musculoskeletal pain                         |
| Jurado-Fasoli et al, <sup>8</sup> 2020 | Spain    | 98                  | Adults                 | Exercise training                | 6 months  | Sleep quality                     | Improved sleep quality                               |
| Díaz-Silveira et al, <sup>9</sup> 2020 | Spain    | 90                  | Working adults         | Mindfulness vs physical exercise | 10 weeks  | Mental health, stress             | Reduced stress, improved mental health               |
| Vilpunaho et al, <sup>12</sup> 2021    | Finland  | 1090                | Urban and rural adults | Various exercise interventions   | NA        | General health outcomes           | Urban participants had better health outcomes        |

**Table 1. Characteristics of the Included Studies (Continued)**

| Source                                | Country      | No. of Participants | Population                           | Intervention                                | Duration | Outcomes                         | Key Findings                               |
|---------------------------------------|--------------|---------------------|--------------------------------------|---------------------------------------------|----------|----------------------------------|--------------------------------------------|
| Fan et al, <sup>14</sup> 2020         | China        | 106                 | Older adults with sleep disturbances | Baduanjin exercise                          | 6 months | Sleep quality, quality of life   | Improved sleep quality and quality of life |
| Raichlen et al, <sup>15</sup> 2020    | US           | 33                  | Older adults                         | Cognitive and aerobic exercise              | 10 weeks | Dual-task walking                | Improved dual-task performance             |
| Aegerter et al, <sup>17</sup> 2020    | Switzerland  | 96                  | Office workers                       | Strength, stretching, and aerobic exercises | 6 months | Productivity, neck pain          | Reduced neck pain, improved productivity   |
| Alotaibi et al, <sup>18</sup> 2021    | Saudi Arabia | 120                 | Health science students              | Exercise education and lifestyle promotion  | 4 weeks  | Knowledge of lifestyle promotion | Increased knowledge and awareness          |
| Johannessen et al, <sup>19</sup> 2021 | Norway       | 855                 | Pregnant women                       | Pelvic floor muscle training                | 3 months | Urinary incontinence             | Reduced urinary incontinence               |
| Wang et al, <sup>20</sup> 2020        | China        | 90                  | Young adults                         | Pedometer-based walking                     | 8 weeks  | Stress, life satisfaction        | Reduced stress, improved life satisfaction |
| Benedetti et al, <sup>21</sup> 2020   | Brazil       | 166                 | Older adults                         | Physical activity program                   | 6 months | Physical activity engagement     | Increased engagement in physical activity  |

Abbreviation: NA, not applicable.

**Table 2. Risk of Bias Assessment of Included Randomized Controlled Trials (Cochrane Tool)**

| Source                                 | Random Sequence Generation | Allocation Concealment | Blinding of Participants and Personnel | Blinding of Outcome Assessment | Incomplete Outcome Data | Selective Reporting | Overall Risk of Bias |
|----------------------------------------|----------------------------|------------------------|----------------------------------------|--------------------------------|-------------------------|---------------------|----------------------|
| Santos et al, <sup>2</sup> 2020        | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Lai et al, <sup>3</sup> 2021           | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Murukesu et al, <sup>4</sup> 2020      | Low                        | Low                    | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Beauchamp et al, <sup>5</sup> 2021     | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Anan et al, <sup>7</sup> 2021          | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Jurado-Fasoli et al, <sup>8</sup> 2020 | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Díaz-Silveira et al, <sup>9</sup> 2020 | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |

**Table 2. Risk of Bias Assessment of Included Randomized Controlled Trials (Cochrane Tool) (Continued)**

| Source                                | Random Sequence Generation | Allocation Concealment | Blinding of Participants and Personnel | Blinding of Outcome Assessment | Incomplete Outcome Data | Selective Reporting | Overall Risk of Bias |
|---------------------------------------|----------------------------|------------------------|----------------------------------------|--------------------------------|-------------------------|---------------------|----------------------|
| Vilpunaho et al, <sup>12</sup> 2021   | Low                        | Unclear                | Unclear                                | Unclear                        | Low                     | Low                 | Moderate             |
| Fan et al, <sup>14</sup> 2020         | Low                        | Low                    | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Raichlen et al, <sup>15</sup> 2020    | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Aegerter et al, <sup>17</sup> 2020    | Low                        | Unclear                | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Alotaibi et al, <sup>18</sup> 2021    | Unclear                    | Unclear                | Unclear                                | Unclear                        | Low                     | Low                 | Moderate             |
| Johannessen et al, <sup>19</sup> 2021 | Low                        | Low                    | High                                   | Unclear                        | Low                     | Low                 | Moderate             |
| Wang et al, <sup>20</sup> 2020        | Low                        | Unclear                | Unclear                                | Unclear                        | Low                     | Low                 | Moderate             |
| Benedetti et al, <sup>21</sup> 2020   | Unclear                    | Unclear                | Unclear                                | Unclear                        | Low                     | Low                 | Moderate             |

## Discussion

This systematic review synthesizes recent RCT evidence on the effects of resistance training, mind-body exercise, and technology-assisted exercise interventions on musculoskeletal and mental health outcomes. Overall, the findings suggest that diverse exercise modalities confer meaningful benefits across occupational, aging, and community contexts, although the certainty of the evidence varies according to intervention type, delivery format, and methodological quality.

### Mechanisms Underpinning the Effectiveness of Exercise Interventions

The observed improvements in musculoskeletal outcomes following resistance and multicomponent exercise interventions are biologically plausible and consistent with established physiological mechanisms. Progressive resistance training enhances neuromuscular activation, muscle strength, and connective tissue resilience, thereby reducing biomechanical strain and perceived fatigue during occupational tasks. These mechanisms likely explain the reductions in fatigue and musculoskeletal pain observed among industrial and office workers following structured resistance or strength-based programs.<sup>2,6</sup> Similar mechanisms may underpin improvements in muscle strength, metabolic outcomes, and physical function among prefrail and older adults participating in lower-limb resistance and multidomain exercise programs.<sup>3,4</sup>

Mind-body exercise interventions appear to exert additional benefits through combined physical, neurobiological, and psychophysiological pathways. Practices such as Baduanjin and mindfulness-based exercise integrate low-to-moderate physical activity with controlled breathing, focused attention, and relaxation. These elements are thought to modulate autonomic nervous system balance, reduce hypothalamic-pituitary-adrenal axis

activation, and promote endorphin release, thereby alleviating stress, improving sleep quality, and enhancing psychological well-being.<sup>10</sup> Consistent improvements in sleep quality and mental health outcomes reported among older adults and working populations support the relevance of these mechanisms.<sup>7-9</sup>

Technology-assisted and digitally delivered exercise interventions introduce additional behavioral mechanisms related to engagement and adherence. AI-assisted programs and online platforms can provide individualized feedback, self-monitoring, and flexible participation, which may enhance motivation and sustained participation. These mechanisms likely contributed to the observed reductions in musculoskeletal pain among office workers and improvements in mental health during periods of restricted mobility, such as the COVID-19 pandemic.<sup>5,6</sup>

### **Cost-Effectiveness and Feasibility in Real-World Health Systems**

From a health systems perspective, many of the effective interventions identified in this review are potentially cost-effective and feasible for large-scale implementation. Resistance training, mind-body exercises, and walking-based programs typically require minimal equipment and can be delivered in group, home-based, or community settings. Such characteristics are particularly advantageous for primary care, occupational health, and community health promotion programs, especially in resource-constrained environments.<sup>1,11</sup>

Digitally delivered and online exercise interventions offer further potential advantages in scalability and workforce efficiency. Once established, online platforms can be delivered to large populations at relatively low marginal cost, reducing the need for repeated face-to-face supervision. Evidence from older adult populations during the COVID-19 pandemic suggests that such approaches can effectively support mental health and maintain physical activity.<sup>5</sup> However, feasibility depends on digital infrastructure, user literacy, and access, which may vary across settings and populations.

Despite these promising features, few included trials directly assessed economic outcomes such as cost-effectiveness or cost-benefit ratios. Consequently, conclusions regarding economic value are indirect and based primarily on intervention characteristics rather than formal economic evaluation. Future studies should integrate health economic analyses alongside clinical outcomes to better inform policy and resource allocation decisions.

### **Equity, Access, and Contextual Considerations**

The findings also highlight disparities in access to exercise interventions, particularly between urban and rural populations. Better health outcomes observed among urban participants may reflect greater access to organized exercise programs, facilities, and supportive environments.<sup>12,13</sup> These disparities underscore the importance of designing flexible, context-sensitive exercise interventions that can be implemented in rural and underserved communities.

While digital delivery may help overcome geographic barriers, it may also exacerbate inequities if access to technology is uneven. Hybrid models combining community-based delivery with digital support may offer a balanced approach to improving reach while maintaining inclusivity.

### **Methodological Considerations and Interpretation of Findings**

Although the overall pattern of findings supports the benefits of exercise interventions, several methodological limitations warrant cautious interpretation. Many included trials

demonstrated an unclear or high risk of bias in domains such as allocation concealment and blinding, reflecting both reporting limitations and the inherent challenges of blinding in exercise-based research.<sup>2, 6, 7</sup> Short intervention durations and limited follow-up periods further restrict inference regarding the long-term sustainability of the observed effects.

Heterogeneity in intervention types, populations, and outcome measures precluded meta-analysis and necessitated a narrative synthesis. As a result, the findings should be interpreted as indicating consistent trends rather than precise estimates of effect magnitude.

### **Implications for Future Research**

Future RCTs should prioritize longer follow-up periods, standardized outcome measures, and transparent reporting to strengthen the certainty of the evidence. Comparative studies examining different exercise modalities and delivery formats, including traditional vs digital approaches, are needed. In addition, incorporating health economic evaluations and implementation outcomes will enhance the relevance of future research for public health policy and practice.

### **Limitations of the Review**

In addition to limitations related to the included studies, several limitations of the review process itself should be acknowledged. First, although a comprehensive search was conducted across 4 major databases, the search strategy was restricted to studies published in English, which may have introduced language bias and resulted in the exclusion of relevant evidence published in other languages. In addition, while the search terms were systematically applied, the absence of database-specific full search strings in the main manuscript may limit exact reproducibility, although the overall search framework was consistent with PRISMA recommendations.

Second, although this review employed independent dual screening and data extraction to reduce the risk of reviewer bias, subjective judgment during study selection and data interpretation cannot be entirely excluded. Disagreements were resolved through consensus and third-reviewer adjudication; nevertheless, some degree of interpretive bias is inherent in narrative synthesis approaches.

Third, while methodological quality was assessed using the Cochrane Risk of Bias Tool, the implications of study-level risk of bias for evidence certainty warrant cautious interpretation. Many included exercise trials exhibited an unclear or high risk of bias in domains such as allocation concealment and blinding, reflecting both reporting limitations and the practical challenges of blinding in exercise-based interventions. Although risk of bias results are now explicitly presented and considered, these methodological constraints may attenuate confidence in the magnitude of the observed effects.

Finally, the decision to conduct a narrative synthesis rather than a meta-analysis, due to substantial heterogeneity in interventions, populations, and outcome measures, limits the ability to quantify pooled effect sizes and formally assess publication bias. Consequently, the conclusions of this review should be interpreted as indicative of overall trends rather than definitive estimates of intervention effectiveness.

### **Future Research Directions**

Future research should focus on addressing the gaps identified in this review. Long-term studies are needed to understand the sustained effects of exercise interventions on health outcomes. Additionally, research should explore strategies to overcome barriers to

physical activity, particularly in underserved and rural communities. Innovative approaches, such as digital and online interventions, hold promise for expanding access to exercise programs and should be further investigated.

## Conclusions

This systematic review indicates that resistance training, mind-body exercise, and digitally delivered exercise interventions are associated with improvements in musculoskeletal and mental health outcomes across diverse populations. Evidence from RCTs suggests benefits in reducing musculoskeletal pain and occupational fatigue, improving sleep quality and psychological well-being, and enhancing physical function among older and prefrail individuals. However, the interpretation of these findings should consider the methodological heterogeneity, variable risk of bias, and generally short follow-up periods observed across the studies. Overall, structured exercise interventions represent a promising approach to supporting musculoskeletal and mental health in occupational and community settings. Future research should prioritize well-designed trials with standardized outcomes and longer follow-up periods to strengthen the evidence base and inform policy and practice.

## Additional Information

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**Supplementary Material:** Download Supplementary S1 from the following link:  
<https://he02.tci-thaijo.org/index.php/ramajournal/article/view/276961/190177>

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