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The Role of Physical Exercise in the Prevention of Musculoskeletal Disorders in Manual Workers: A Systematic Review and Meta-Analysis

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Summary

Work-related Musculoskeletal Disorders (WMSDs) are the most common occupational health problem in the European Union. Physical exercise interventions have been investigated to prevent WMSDs in many sectors. Therefore, we aimed to assess the effect of physical exercise on manual workers for the primary and secondary prevention of WMSDs. We conducted a systematic search of the literature, and papers were included if the participants were adult employees exclusively engaged in manual labor tasks, non-acute physical exercise intervention, pain, disability, physical functioning, or health-related quality of life outcome, with pre-post intervention measurements. We retrieved 10,419 unique records and included 23 studies. A random effect meta-analysis was conducted on the studies with a control group design, using a three-level model to estimate the pooled effect for pain outcomes (g=0.4339, 95% CI: 0.1267–0.7412, p<0.01), and a two-level model for disability outcomes (g=0.6279, 95% CI: 0.3983–0.8575, p<0.0001). Subset analysis revealed a moderate-to-large effect on the VAS outcome (g=0.5866, 95% CI: 0.3102–0.8630, p<0.0001). Meta-regression on pain outcomes revealed a significant effect for sex, age, study quality, and body segments tested. The analyses on all outcomes except VAS showed substantial heterogeneity ($I2_{pain}$=93%, of which 72% at the study level, $I2_{disability}$=78%, and $I2_{vas}$=56%, of which 44% at the study level). Physical exercise programs seem to have a positive effect on pain and disability stemming from WRMSDs in manual workers.

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1. Introduction

Work-related Musculoskeletal Disorders (WRMSDs) affect muscles, tendons, ligaments, nerves, and other soft tissues in the body. Musculoskeletal Disorders (MSDs) are the most common work-related health problem in the European Union, and workers in all sectors and occupations can be affected [1]. Indeed, looking at the EU Labour Force Survey (LFS) [2] ad hoc modules from 2007 and 2020, reported rates of self-reported MSDs across 27 EU countries increased from 54.2% to 60.1% in persons from 15 to 64 years of age, within this time frame [3]. Additionally, in the 2023 European Agency for Safety and Health at Work report, the prevalence of MSDs is not decreasing, as could be expected due to the sectoral shifts of the workforce from industry and agriculture to services [4]. Indeed, the authors of the EU-OSHA study 'Work-related musculoskeletal disorders: why are they still so prevalent?' consider several reasons for this: the ergonomic burden shifted to other tasks like handling patients instead of handling heavy loads, more inactivity with other musculoskeletal consequences, more time pressure, an ageing workforce, and inadequate work organization and contractual arrangements [3].

Moreover, WMSDs result from various factors, with the work environment and performance playing a significant but varying role in causing the disorder. Occupational factors such as repetitive tasks, awkward postures, forceful exertions, prolonged sitting or standing, and other secondary risk factors can cause or worsen MSDs.

Examples of these disorders include carpal tunnel syndrome, tendonitis, back pain, and discomfort in the neck and shoulders; these conditions can cause pain, restrict mobility, and impair functionality, affecting an individual's ability to perform job tasks effectively. To manage and reduce the risk of WMSDs, it is crucial to implement ergonomic interventions, provide proper training, and foster a healthy work environment. Furthermore, peer-reviewed literature about the effectiveness of workplace interventions in preventing upper extremity musculoskeletal disorders and symptoms concluded that many intervention types did not meet the criteria for high or moderate levels of evidence [5]. While it may be inferred that the interventions were ineffective, it is important to note that the current scientific evidence is insufficient to support their recommendation. For example, job stress management training, EMG biofeedback training and workstation adjustment alone interventions had a moderate level of evidence of no effect for upper extremity MSDs outcomes [5].

Another systematic review debated participatory ergonomic intervention facilitators and barriers that could be decisive for a good improvement plan [6].

In addition, ergonomic risk assessment is estimated by several methodologies based on the type of task, environment, or legislation. For example, for manual handling, there are NIOSH (National Institute for Occupational Safety & Health) lifting equations [7], Snook & Ciriello procedure [8], Key indicator method (KIM-MHO) [9], and others. This wide heterogeneity of evaluations and a limited or non-existent consideration given to the sex factor in popular ergonomic assessment methods [10] could be one or generate unhelpful resolutions for both genders.

Another type of intervention used to prevent WMSDs is physical exercise (PE), which seems to reduce low back pain with only 10–15 minutes of adapted exercise performed 3–5 days per week by office workers [11]. Other papers have also investigated different kinds of exercise and working populations; for example, da Costa & Vieira [12], in their review, highlighted mixed findings but demonstrated some beneficial effects of stretching in preventing work-related musculoskeletal disorders. Moreover, Martinez [13], in his review, affirmed that the implementation of a workplace exercise program is of great value both for employees, who will improve their quality of life, and for the company, given that workers will be more satisfied.

Finally, the significant impact of physical demands at work on the development and persistence of WMSDs is widely recognized. While some individuals can continue working despite having MSDs, for others, it could be a diminished work ability, increased sick leave, and premature withdrawal from work [14]. Therefore, the main purpose of our study is to determine the effectiveness of exercise interventions (type, frequency, duration) in contributing to the primary and secondary prevention of WMSDs in manual workers.

2. Methods

The review protocol was initially registered on PROSPERO under the ID: CRD42022302772, and the review was written following the structure given by the PRISMA statement [15]. A systematic search was conducted on PubMed, Scopus, CINAHL, Web of Science and EMBASE using a search string composed of MeSH terms and free keywords identified by reading relevant papers on the subject, such as Stevens et al. [16] and Gram et al. [17]; the full search string used on PubMed was also used on the other search instruments by adapting the syntax and accounting for their thesauri or lack thereof (All search strings are available in the supplementary material A).

Eligibility criteria were established using the PICO-S reporting system [18]:

- Population: Employees engaged in manual labor tasks and exposed to biomechanical overload risk factors (e.g., material handling, repetitive movements of upper arm), from 18 to 65 years old. Studies that included both manual and office workers were excluded, as were studies exploring nurses, doctors, and other healthcare professionals, given that they are included in a different risk assessment category.
- Intervention: Non-acute physical activity (PA) interventions.
- Comparator(s): Employees exposed to different modalities of physical activity and/or no intervention.
- Outcome(s): Any evaluation of pain and/or functional impairment, with evaluations of physical functioning and health-related quality of life as secondary outcomes, with pre-post intervention measurements of the outcome (Standardized mean of difference measures).
- Study type: Pilot study, RCT, non-RCT, exploratory study, Randomized pilot trial.

We only included papers written in English and did not impose a publication year restriction in the criteria. The first round of searches was conducted in November 2021, and all records retrieved were uploaded on Rayyan (https://www.rayyan.ai/) [19], deduplicated, and screened by title and abstract. We then retrieved all papers that met our eligibility criteria and that were available and read the full-text articles for definitive inclusion. The screening process was conducted independently by F.F. and B.V., and disagreements were resolved by discussion with P.D.

Backward and forward Citation searching was also conducted on the included papers (on PubMed and Scopus), although no additional articles could be retrieved.

The same two authors extracted data from the included papers using an adapted version of the Cochrane data collection form (template form available in the supplementary materials):

- Study identifiers: title, first author, year, journal, study ID.
- Type of study (blinding, randomization, group homogeneity).
- Participants (number of participants, age, sex, workplace).
- Type of intervention (modality and setting).
- Exercise intervention parameters and duration (weeks).
- Comparison group intervention and/or control group data.
- Withdrawals and exclusions.
- Main outcome and measurement (methodology used and numerical measures).
- Secondary outcomes, if there were any.

The included studies were then divided between "pain and disability", "Health-related physical fitness," and "Cardiological parameters" outcomes and based on the typology of intervention received: "resistance training", "stretching and mobility training", "comparison of different interventions between groups", and a catch-all "other" category.

The quality of the studies was analyzed by V.B. and F.F. using a nine-criteria checklist adapted from the Cochrane Collaboration Back Review

Group [20], and studies with a positive (+) score in at least 5/9 items were considered as "high-quality".

Pain and disability outcomes were further split into "pain" (VAS measures, NMQ, etc.), "disability" (DASH, SPADI, etc.), and "effort" (RPE measures) outcomes.

Only the studies that included an intervention group and a true control group (not performing some physical activity) were included in the meta-analysis. Data was prepared on a standard Excel sheet (Microsoft 365, 2017) for a three-level meta-analysis.

All pre/post outcome data were converted or estimated into means and standard deviations (SD), specifically, to estimate the mean and S.D. of the outcomes in "Moreira-Silva_2014," the methods outlined by Wan et al. [21] employed. The control groups in "Ludewig_2002" were combined using the formulas in the Cochrane Handbook [22], chapter 6, table 6.5.a. In contrast, the control group in "Weyh_2020" was split into 2 equal groups to match the two intervention groups (strength and endurance training, respectively) to avoid "double counts", as recommended in the Cochrane Handbook, chapter 23, section 3.4. Similarly, "Zebis_2011" was split into two entries as divided in the paper, "cases" and "non-cases" (sample characteristics and outcomes were already reported separately, and no data conversion was required).

Effect sizes (ES) for each outcome and their variance were estimated using the pooled pre-test S.D. described by Morris S.B. [23].

Pre and post-intervention correlation coefficients were calculated using the methods provided by the Cochrane Handbook, chapter 6, section 2.5.8 when enough data was available in a study (SD pre-intervention, SD of change from baseline), and the resulting coefficients were used to assign a correlation coefficient to all other studies.

To estimate the overall effect size, a three-level model, with a single ES nested at the study level, was fitted using the restricted maximum likelihood (REML) method. The use of a three-level model was tested using the information criteria AIC (Akaike information criteria), BIC (Bayesian information criteria), and AICc (AIC corrected) to support the use or rejection of a three-level structure. Sensitivity analysis was performed with different correlation coefficient imputations. The results for pain outcomes were aggregated at the study level (maintaining the same pooled estimate) to produce a readable forest plot.

Meta-regression was carried out on pain outcome data (due to the limited number of disability outcomes) by testing one moderator at a time and estimating their significance with the restricted maximum likelihood test. A subset analysis was conducted, including only the VAS outcomes. Heterogeneity was estimated using the Cochran's Q and I^2 statistics. All analyses were then repeated after excluding one study that reported extremely high ES.

The pooled ES were categorized as "small" (< 0.39), "moderate" (0.40–0.59), "large" (0.60–0.79), and "very large" (≥ 0.80). I^2 values smaller than 50% of 50 to 75%, and larger than 75% were considered to indicate low, moderate and substantial levels of heterogeneity. The statistical significance threshold was set at $p<0.05$. All statistical analyses were performed with the statistical software R, version 4.3.2 [24] and the metafor package [25].

3. Results

A total of 15,778 records were retrieved from the searches and, after deduplication and abstract screening, 85 papers were retrieved and assessed for inclusion: 5 were not available to us, 5 were only available as abstracts, 7 were not in English, 32 had the wrong population, 11 didn't include a physical activity intervention, 3 didn't include any outcomes of interest, and 4 chose a study design outside of our criteria. Ultimately, 23 papers were included in the review and 14 in the meta-analysis (Figure 1), and relevant data was extracted.

17 papers were classified as "high quality", with the "upper limb" study of Sundstrup et al. [26] receiving a perfect score, and 6 as "low quality"; the mean score was of 6.1±2.0 out of 9, showing an overall good quality of the included papers; the results of this analysis are summarized in Table B1, available in the Supplementary material B.

3.1. Descriptive Analyses

As many as 2,454 participants were analyzed across the included studies, with an overall mean

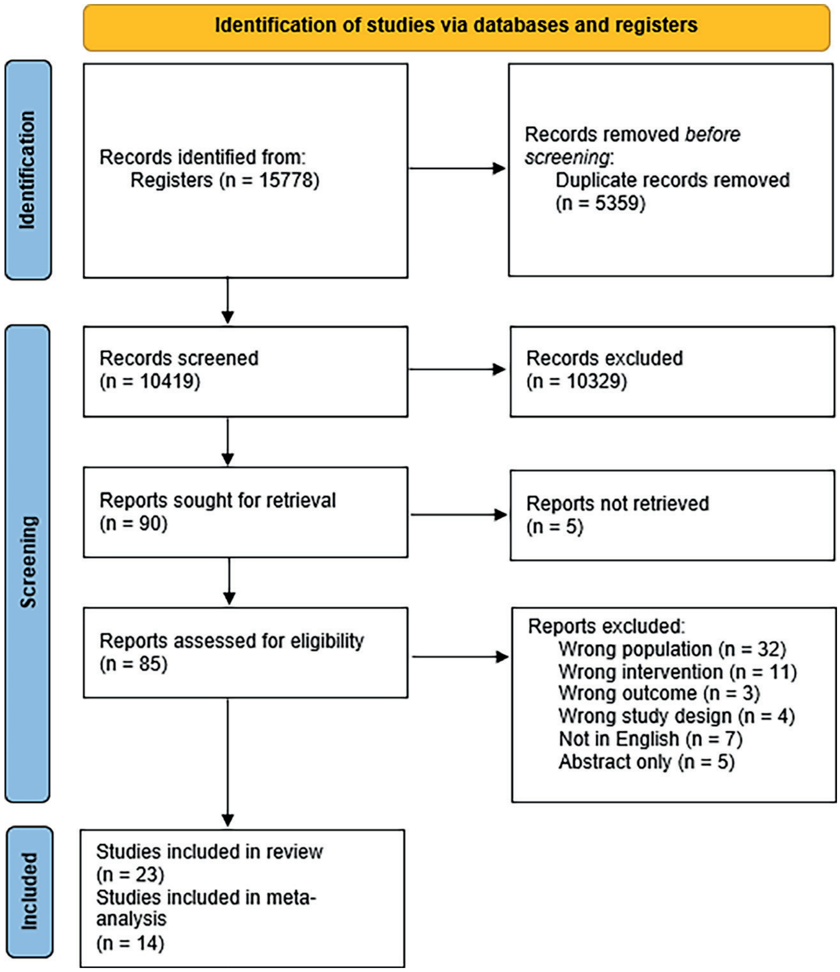

Figure 1. PRISMA Flowchart.

age of 41.58±9.39 years. 9 papers [27-35] implemented a resistance training intervention for a total of 1507 participants (1076 coming from Pedersen et al. [32] and Zebis et al., [33], 537 each); only one [36] carried out a pure stretching intervention, with 40 participants; 6 studies [26, 37-41] compared different intervention across multiple groups (356 participants total); finally, there were 7 more studies [17, 42-47] that implemented a number of other different or multimodal protocols, analyzing 551 participants overall. A summary of the studies' interventions and outcomes are available in the supplementary material B, in tables B2 and B3, respectively.

Mean (±SD) duration of intervention was 18±12.9 weeks (range: 6-47 weeks), with a mean frequency (when it was reported) of 3±1.2 days per week.

The RT interventions that were implemented were mainly specific training protocols, focusing on the shoulders, arms, and, to a smaller extent, spinal erectors. Only two studies with a RT intervention used a more general training approach, Rasotto et al. [31] and Gobbo et al. [27].

The stretching-only intervention applied by Bertozzi et al. [36] was aimed instead at the lumbar region and lower limbs.

The 7 papers with various interventions employed combined interventions of stretching and resistance training, or cryotherapy [45], or added compensatory exercises [47], and one carried out an exercise protocol based on a guidebook published by the Finnish Institute of Occupational Health [46].

Lastly, the interventions compared against each other in the papers with more than one intervention group are reported in Table B4, available in the Supplementary material B.

3.1.1. Effect on Pain

All included papers except for one [34] measured at least one outcome in the pain and disability domain, with 19 of those reporting at least one statistically significant ($p<0.05$) favorable pre-post difference in the intervention group(s).

The most prevalent pain outcomes measured were VAS (visual analogue scale) [48] and DASH (disability of the arm, shoulder, and hand questionnaire) [49] scores. Other outcomes relating to pain and/or disability and or work ability were used, such as: WAI (Work Ability Index) [50], SRQ (Shoulder Rating Questionnaire) [51], SPADI (Shoulder Pain and Disability Index) [52], NMQ (Nordic Musculoskeletal Questionnaire) [53], NPDS (Neck Pain and Disability Scale) [54], RPE during work activities, ODI (Oswestry Disability Index) [55] and BPI (Brief Pain Inventory) [56].

Specifically, 15 studies looked at outcomes relating to pain and disability in the upper limbs, shoulder and/or neck, with a mean duration of intervention of 17.5±12.8 weeks, using the VAS score or one or more of the scales listed above, that ask the participant about their pain in the last week or month, indicating more stable benefits, as opposed to acute effects, measured immediately post-training session.

3.1.2. Effect on HR-Physical Fitness and Cardiovascular Parameters

Among the included studies, 15 additionally measured health-related physical fitness and/or cardiovascular parameters, including the Senior Fitness Test, Hand grip and other physical strength tests, mobility assessments, resting heart rate and blood pressure measurements. 12 of those studies reported one or more statistically significant ($p<0.05$) favorable pre-post difference in the intervention group(s) for HR-physical fitness, and 1 reported a significant effect for cardiovascular parameters [39].

3.2. Meta-Analyses

When the first round of analyses was concluded, one study [43] was excluded because of the extremely high ES reported (4.62 and 5.52 for VAS of the shoulder and SPADI score, respectively), the lack of important information, such as the sample mean age and the timing of the intervention, and its overall poor quality (2/9). All analyses were then repeated without this study. The original analyses are available upon request. Only 3 papers included an "effort" outcome. Therefore, meta-analysis was conducted only on "pain" and "disability."

3.2.1. Effect on Pain

Exercise interventions resulted in a significant reduction in pain, with a pooled standardized mean change of 0.4339 (95% CI: 0.1267–0.7412, $p<0.01$), indicating a moderate effect of an exercise intervention on pain outcomes of workers employed in manual labor based on 49 unique outcomes nested in 13 studies, with a total sample size of 1,583 participants across studies. Information criteria and the likelihood ratio test support using a three-level model ($\chi^2=19.32$, $p<0.0001$).

Significant heterogeneity was found ($I^2_{pain}=93.2$ %), and variance decomposition reveals that 71.9% of the variance comes from heterogeneity between studies ($I^2_{level2}=21.4\%$, $I^2_{level3} = 71.9\%$).

The funnel plot (Figure B1, Supplementary material B) shows moderate asymmetry towards the null effect (each point is an outcome, outcomes from different studies are shown with different colors) and high heterogeneity between studies.

The data was then aggregated at the study level, maintaining the point estimates and confidence intervals, to produce the forest plot in Figure 2.

3.2.2 Effect on Disability

Exercise interventions resulted in a significant reduction in disability outcomes, as measured wit questionnaires and scales such as the DASH, NPDS-I, and WAI, with a pooled standardized mean change of 0.6279 (95% CI: 0.3983–0.8575,

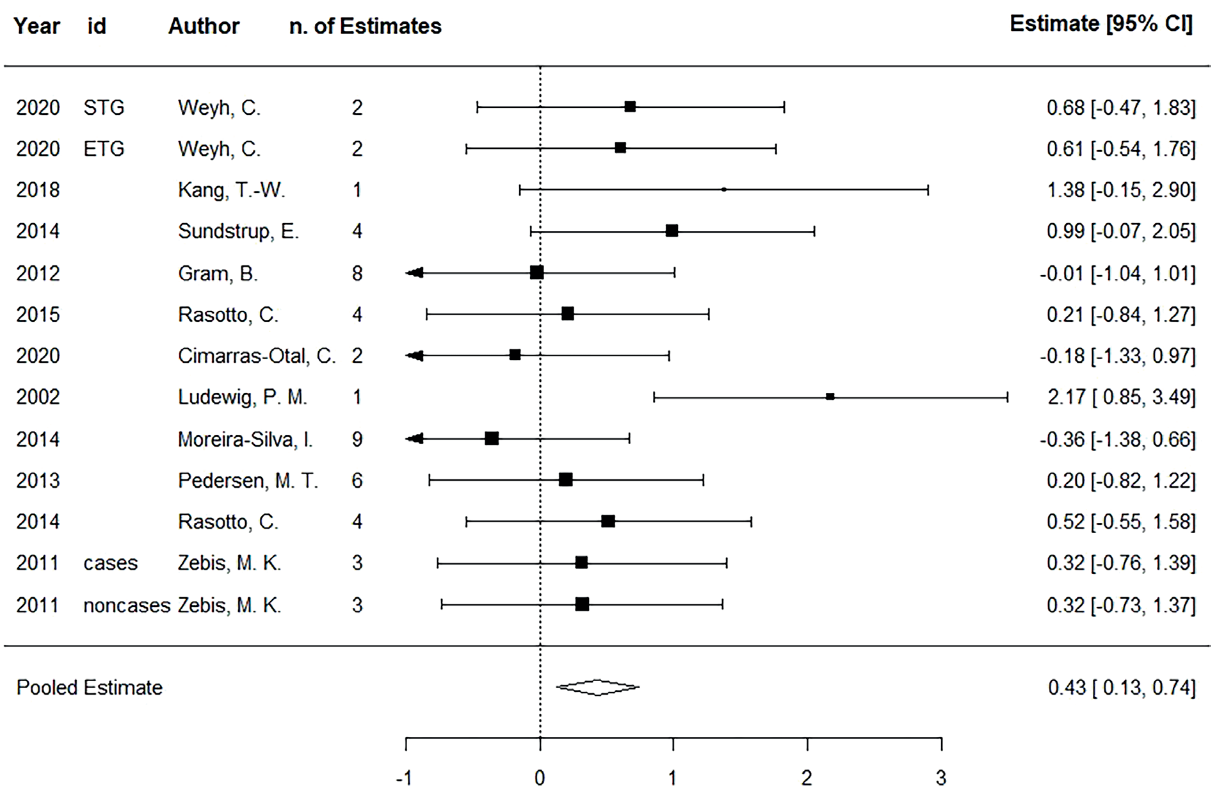

Figure 2. Forest plot for (aggregated) pain outcomes.

$p<0.001$), showing a large effect of exercise intervention on disability scores of workers employed in manual labor. Information criteria and the likelihood ratio test reject the choice of a three-level model ($\chi^2=2.34$, $p=0.13$), therefore, a two-level random effect model was used to fit the model, with 15 outcomes coming from 9 studies, for a total of 1035 participants (Figure 3).

Significant heterogeneity was found for disability outcomes ($Q=63.86$, $I^2=78\%$).

The funnel plot (Figure B2, Supplementary material B) shows slight asymmetry towards positive effects and high heterogeneity between studies.

3.2.3. Meta-Regression

The moderators tested were: year of publication, randomization (RCT or non-randomized), activity level (sedentary or active participants), mean age of participants, baseline differences between groups, type of intervention (strength, aerobic, combined or other modalities of training), duration and timing of the intervention, body part tested (neck, back, upper limbs, lower limbs, or whole-body). Among these, sex, age, and body part (whole body only) showed a significant effect.

Specifically, when comparing studies that included only men, only women, or both, men-only studies showed a pooled estimate of $g=0.8279$ (95% CI: 0.1916–1.4642, $p=0.0108$).

The mean age of participants had a significant moderating effect, with larger ES for studies that recruited older subjects (intercept ES=-5.8440, equivalent to a mean age of 0 years, increased by 0.1484 for each additional year of age; figure 4, cut at 30 years old for clarity).

Only pain outcomes relating to the whole body (such as averaged VAS results) had a significant effect on the model ($p<0.001$), however, this moderator had unbalanced classes, with tests for the upper

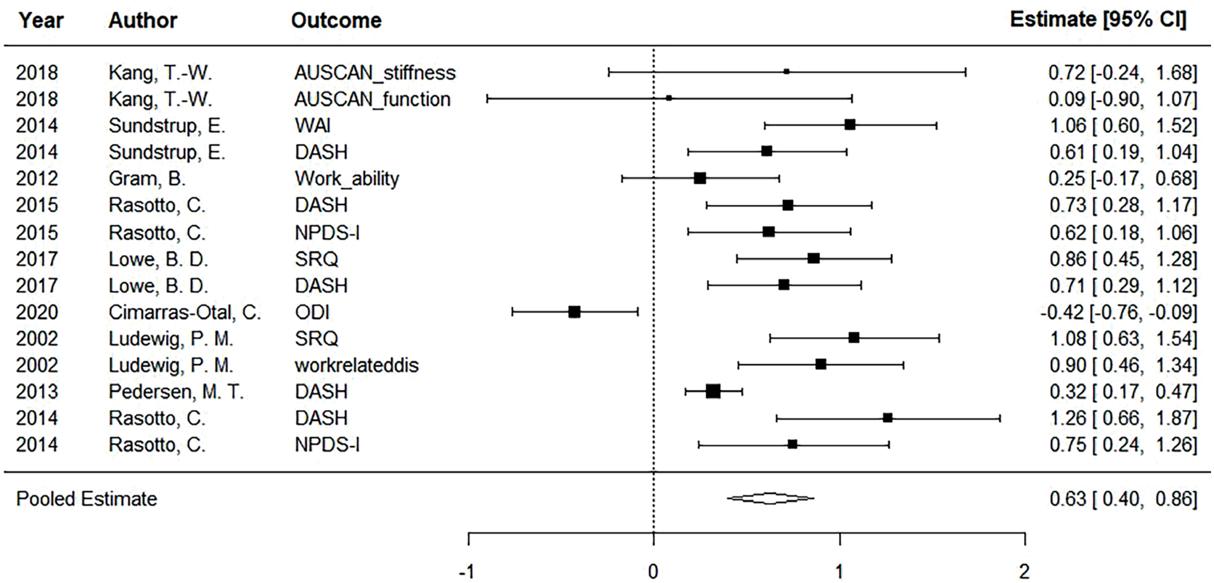

Figure 3. Forest plot for disability outcomes.

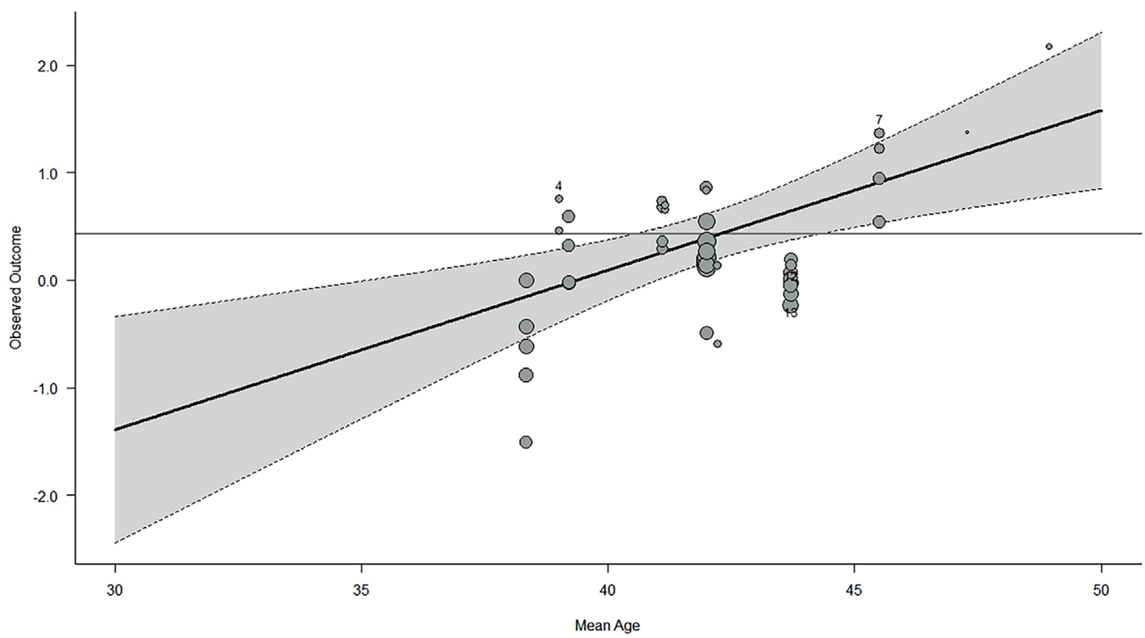

Figure 4. Regression line for Mean age. The grey horizontal line is set at 0.4339, the ES of the full model for pain. Each point represents an outcome, with larger points representing studies with heavier weight.

body comprising almost 50% of the pain outcomes (23 out of 49), undermining the usefulness of this particular result. Similarly, study quality was a significant moderating factor, with a pooled estimate of g=0.4984 (95% CI: 0.2097–0.7870, p<0.001) for studies of good quality (score≥5), and of g=-0.3558 for studies of poor quality.

Additionally, for the type of intervention, strength training displayed a trend towards significance (p=0.0503).

3.2.4. Subset Analysis

A subset of the dataset was constructed, including only measures of VAS results (16 outcomes nested within 5 studies, 271 total participants).

The pooled standardized mean change, based on a three-level model, was g=0.5866 (95% CI: 0.3102–0.8630, $p<0.0001$), showing a moderate-to-large effect of exercise intervention on the VAS score of workers employed in manual labor (Figure 5). This subset analysis shows much lower heterogeneity, with I^2=56%, with 44% of the total variation coming from between-studies heterogeneity (I^2_{level2}=11.54%, I^2_{level3}=44.39%). Information criteria and the likelihood ratio test support using a three-level model ($\chi^2 = 4.16$, $p < 0.05$). The funnel plot presents good symmetry (Figure B3, Supplementary material B).

4. Discussion

This systematic review aimed to assess the effect of physical exercise intervention on primary and secondary preventions in work-related musculoskeletal disorders. Data showed a moderate positive effect on various pain outcomes and a large effect on disability as measured with specific questionnaires, such as the DASH and the ODI. Results in this systematic review and meta-analysis are in accordance with those extracted by Moreira-Silva et al. [57], who conducted a meta-analysis and found moderate quality evidence of a positive effect of physical activity interventions on employees (without excluding papers based on work environment) on musculoskeletal pain in the neck/shoulder region, and only low-quality evidence for other sites of WMSDs (low-back, arms, wrist, etc.). A point of strength of the current systematic review is that, by limiting our population of interest to manual workers, we reduced heterogeneity in the participants' baseline conditions and exposure to work-related risk factors. Most of the included papers measured at least one outcome relative to pain and disability in the upper limb: this is not surprising, given that the shoulder has a high prevalence of WMSDs [58, 59]. Notably, instead, only 3 studies used questionnaires and scales directly investigating the lumbar region, another of the most common sites of WMSDs, and low back pain, such as the Oswestry disability index.

The main results of the meta-regression were the significant effects of sex and age:

The effect of exercise on pain appears to be greater in male workers. However, in the present meta-analysis, we could only compare studies recruiting only men versus studies that didn't impose

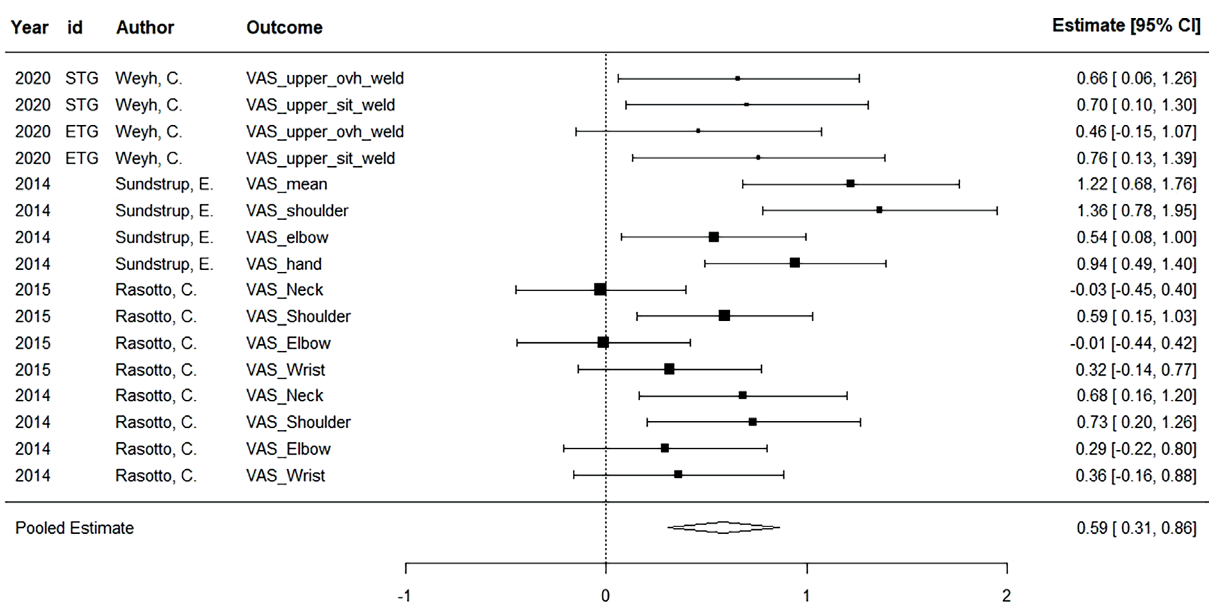

Figure 5. Forest plot for VAS outcomes.

a gender restriction on the participants. Only one study [35] was conducted on a female-only sample. This is part of the broader issue of the underrepresentation of women in both clinical and exercise trials [60-62]. More experimental trials are needed to characterize better the differences and needs of women involved in manual industrial work.

The significance of age as a moderator is less surprising. However, even though our inclusion criteria were set to include participants from 18 to 65 years old, it must be noted that in the included studies, the age range was much smaller, 28-48 years old, which somewhat limits the validity of the meta-regression data for this moderator.

As a side note, even though we imposed no restriction on publication year, all the included papers were published in the last 20 years, and more than 60% of them in the last decade. This hints at how recent the academic interest in the subject is and how many lines of research are open in this particular field. Indeed, in recent years, there has been a fast-growing trend in the number of RCTs evaluating the effectiveness of preventive interventions in occupational health [63].

We also looked at the effects on physical fitness and cardiovascular parameters, which, as was to be expected, were positively impacted in nearly all the interventions analyzed. It is also interesting to notice that there seems to be a qualitative correlation between significant effects on musculoskeletal pain and fitness, which would imply either a direct link between the two, as investigated by Ciolac & Rodrigues-da-Silva [64], or that more intensive exercise protocols could provide more significant results for pain and MSDs, that is, the improvements in HR-Physical fitness could be used as a proxy for exercise volume and intensity.

This leads to the first limitation of this review: the intervention protocols were at times poorly described, often lacking key training variables such as total volume or relative intensity (e.g., "The group sessions consisted of moderate worksite exercise based on a guidebook published by the Finnish Institute of Occupational Health"); other interventions were only loosely described by the objective or rationale of the exercise prescription or the muscles and joints involved in the exercise program (e.g., "nine easily-executed exercises to promote stretching and strengthening of soft tissues responsible for spinal stability, especially lumbar stability"). Furthermore, only 3 of the included papers reported attendance to the training program. This limited our ability to compare different interventions across studies and perform meta-regression on training variables. Future papers in this field should provide more accurate descriptions of training variables (volume, intensity, frequency, rest, exercise selection, etc.) in order to better compare interventions across studies, which in turn would allow us to extrapolate the data and provide more explicit recommendations for exercise prescriptions. This last point would also be of interest to the companies applying for these PE programs, as, with more data, it may be possible to derive the minimum effective training volume for the outcomes of interest (i.e., how little time could be spent on these programs to obtain a reduction in work-related injury risk).

The described interventions were generally of simple implementation and required little to no equipment: elastic bands, mats, and a small space to move safely in. All intervention types (resistance training, stretching, aerobic, multimodal, etc.) appeared similarly effective at reducing pain outcomes, with strength training showing a slightly greater effect.

The mean quality of the included papers was good nonetheless, and only 4 studies didn't implement a randomization process, which corroborates the findings of this systematic review. Noticeably, the studies with good quality showed a significantly higher effect on pain compared to the studies with poorer quality. A further study quality analysis could be conducted using tools more tailored towards PE studies, such as the TESTEX scale [65]; we would expect such an analysis to return worse results relative to study quality.

An interesting approach was used by Cheng & Hung [37], who compared clinical-based vs workplace-based "work-hardening" programs (which, again, were just generally described) as part of workers' rehabilitation after an injury. To the best of our knowledge, there are very few papers directly comparing the effects of PE intervention at the workplace against clinical or home-based

PE interventions. Workplace PE programs have the advantage of being easier to monitor, could have higher adherence if the exercise is performed as part of active breaks or shorter, additional PE breaks, and could be perceived by the workers as less time-consuming; therefore, future research investigating if their effects on pain, disability, and HR-physical fitness is comparable to "leisure time PE" could provide a foundation for suggesting their implementation to companies. Furthermore, workplace PE could supplement manual handling training, which was found to be largely ineffective and of questionable value [66, 67].

A second limitation of the current meta-analysis is the large heterogeneity present both for pain and disability outcomes. This could be ascribed in part to the large number of different scales and questionnaires employed and, in part, to the large variance of most of the outcomes, as can be gleaned from the forest plots in Figures 2, 3, and 5. This large amount of between-study variation reduced the certainty of the pooled estimate and the validity of its interpretation.

Another limitation is that even though the ability to exercise is free from acute musculoskeletal diseases was an inclusion criterion, only one study [33] performed separate analyses for "cases vs. non-cases" that is, participants with ongoing symptoms of WRMSDs and participants free of WRMSDs. Because of this, we can't differentiate between the prescription of an exercise program as primary vs secondary prevention for the development of WRMSDs. Future research could improve upon our work by performing separate analyses between healthy and symptomatic participants.

Visual inspection of the funnel plots (Figures B1, B2, B3, Supplementary material B) does not reveal clear asymmetries that could be interpreted as a sign of publication bias.

While the present review focused on WMSDs and the effects on HR-physical fitness, three of the included papers also measured outcomes relating to mental health, physical exercise and improved physical fitness are known to have a positive effect on mental health [68] in the general population, and their effect on the psychosocial well-being of workers has also been investigated in other fields, for example by [69] in teachers, by [70] in health care workers, and by [71] in office workers.

Particularly, Christensen and Justesen looked at Presenteeism (or "sickness presenteeism"), a relatively novel concept, loosely described as "attending work while ill", or sometimes conflated with its consequence of lost productivity for the company [72], even though there isn't a univocally accepted definition. For the individual, presenteeism usually means a slower recovery from illness, worse health outcomes, and a reduced quality of life. A future line of research could focus on investigating the effects of PA on reducing not just sick leaves [73] but sickness presenteeism as well, as advised in the closing remarks of the recent review on PA and presenteeism by Hervieux et al. [74]. Particularly, PA interventions could reduce costs for companies by reducing the time for recovery and symptoms of MSDs, thus lowering the economic burden of reduced productivity due to working while ill.

Finally, two of the included papers [28, 37] also measured outcomes regarding psychosocial factors, such as "Social support" and "Psychological demands, although in both cases, these factors were only measured at baseline and not at post-intervention. Psychosocial factors can have a significant influence on the worker's health and job performance and can play a role both in the development of WMSDs and the return to work after a WMSD is reported [75].

5. Conclusion

The results of this review provide an overview of the effectiveness of physical exercise programs in reducing musculoskeletal pain and disability in manual workers.

Based on these results, exercise programs seem to have a positive effect on pain and disability stemming from WRMSDs in manual workers. Even though most of the included studies were of "good quality", the substantial heterogeneity between studies limits the certainty of our conclusion. We believe that our results and recommendations could provide a starting point to guide future research in this field and, eventually, to update company policies and help disseminate the implementation of PE programs for manual workers.

SUPPLEMENTARY MATERIALS: Supplementary material A: search strategies. Supplementary material B: additional tables and figures.

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