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REVIEW ARTICLE

# Resistance Training and Mortality Risk: A Systematic Review and Meta-Analysis

Prathiyankara Shailendra, BMedSci,[1,2] Katherine L. Baldock, PhD,[1,2] L.S. Katrina Li, PhD,[2] Jason A. Bennie, PhD,[3] Terry Boyle, PhD[1,2]

**Introduction:** This study aimed to systematically review and meta-analyze the relationship between resistance training and all-cause, cardiovascular disease, and cancer mortality.

**Methods:** Systematic review and meta-analysis following PRISMA guidelines (International Prospective Register of Systematic Reviews Registration Number CRD42019136654) was conducted. MEDLINE (OVID), Embase, Emcare, SPORTDiscus, The Cochrane Library, and SCOPUS were searched from inception to June 6, 2021. Included studies reported resistance training as the exposure and all-cause mortality, cardiovascular disease–specific mortality, and/or cancer-specific mortality as outcome/s. Only studies conducted among nonclinical adult populations (aged ≥18 years) and written in English were included.

**Results:** A total of 10 studies were included in the meta-analyses. Compared with undertaking no resistance training, undertaking any amount of resistance training reduced the risk of all-cause mortality by 15% (RR of 6 studies=0.85; 95% CI=0.77, 0.93), cardiovascular disease mortality by 19% (RR of 4 studies=0.81; 95% CI=0.66, 1.00), and cancer mortality by 14% (RR of 5 studies=0.86; 95% CI=0.78, 0.95). A dose−response meta-analysis of 4 studies suggested a nonlinear relationship between resistance training and the risk of all-cause mortality. A maximum risk reduction of 27% was observed at around 60 minutes per week of resistance training (RR=0.74; 95% CI=0.64, 0.86). Mortality risk reductions diminished at higher volumes.

**Discussion:** This systematic review and meta-analysis provides the strongest evidence to date that resistance training is associated with reduced risk of all-cause, cardiovascular disease, and cancer-specific mortality. More research is needed to determine whether any potential mortality benefits gained from resistance training diminish at higher volumes.
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## INTRODUCTION

Cardiovascular diseases (CVDs) and cancers are the leading cause of death globally, accounting for an estimated 32% and 17% of all reported deaths in 2019, respectively.[1] Physical inactivity is a key modifiable risk factor for the prevention and management of CVD and cancer.[2] At present, most epidemiologic evidence on physical activity and health is based on studies assessing the health benefits of moderate-to-vigorous intensity physical activity (MVPA) (for example, walking, cycling or running). In brief, regular engagement in MVPA is recognized as a strong protective factor against a wide range of health outcomes, including the risk of CVD[3] and some cancers[4] as well as the risk of CVD mortality, cancer mortality, and all-cause mortality.[2]

For optimal health and wellbeing, the 2020 WHO physical activity guidelines recommend that adults take

From the [1]Australian Centre for Precision Health, University of South Australia, Adelaide, Australia.; [2]UniSA Allied Health & Human Performance, University of South Australia, Adelaide, Australia; and [3]Physically Active Lifestyles Group, Centre for Health Research, University of Southern Queensland, Toowoomba, Australia

Address correspondence to: Terry Boyle, PhD, Australian Centre for Precision Health, University of South Australia, Level 8 South, SAHMRI, Building, North Terrace, Adelaide 5000, Australia. E-mail: terry.boyle@unisa.edu.au.

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part in 150–300 minutes of moderate-intensity physical activity or 75–150 minutes of vigorous physical activity per week.[5] The WHO physical activity guidelines also recommended that adults participate in muscle-strengthening activity at least 2 days per week.[5] Resistance training also referred to as strength- or weight-training or muscle-strengthening activity is a common activity/exercise mode that is performed with the purpose of increasing muscle strength, endurance, and power by specifically targeting the musculoskeletal system.[6] Systematic reviews and meta-analyses of controlled exercise studies have shown that resistance training is independently associated with a range of cardiometabolic,[7,8] musculoskeletal,[9,10] and mental health benefits.[11,12] However, less is known about the benefits of resistance training for reducing the risk of all-cause mortality, CVD mortality, and cancer mortality, particularly compared with the large body of epidemiologic evidence on the benefits of MVPA for these outcomes.[13]

A systematic review of studies published up to 2018 by Saeidifard et al.[14] found that performing any amount of resistance training was associated with 21% lower all-cause mortality than doing none ($n$=6 studies). The review also found a 40% risk reduction in all-cause mortality among those performing resistance training in conjunction with MVPA compared with that among those not performing either of these activities, and this risk reduction was greater than was observed for performing either of these activities alone. The results of the review also provided some evidence that resistance training may be associated with risk reductions for CVD mortality and cancer mortality, although the summary estimates were limited because these were only based on 4 and 2 studies, respectively.[14]

Since the systematic review by Saeidifard and colleagues,[14] several additional studies have reported on the relationships between resistance training and all-cause, CVD, and cancer mortality.[15-17] As such, there is a need for an updated systematic review to consolidate the growing body of research on the association between resistance training and mortality, particularly the evidence for CVD mortality and cancer mortality, and to better understand the dose−response relationship between resistance training and mortality. Updated research on the associations between resistance training and mortality outcomes will provide information critical to the development of future physical activity guidelines, especially regarding the nature of the dose−response relationship.

The aim of this systematic review and meta-analysis was to examine the relationships between resistance training and the risk of all-cause mortality, CVD mortality, and cancer mortality among the general adult population. This review also examined the dose−response relationship between resistance training and mortality outcomes and whether the joint association of resistance training and MVPA confers greater mortality-related benefit than either MVPA or resistance training alone.

## METHODS

### Protocol and Search Strategy

This systematic review follows the PRISMA guidelines[18] and was registered with the International Prospective Register of Systematic Reviews database (registration number CRD42019136654). Initially, we planned to include cancer risk outcomes in addition to mortality outcomes in this review. However, studies on cancer risk outcomes were excluded after the data extraction phase because of the publication of a review on those outcomes.[19]

With the aid of an academic librarian, a systematic search for peer-reviewed articles published up to June 6, 2021 was conducted using an amalgamation of keywords and Medical Subject Headings–controlled vocabulary in the following databases: MEDLINE (OVID), Embase, Emcare, SPORTDiscus, The Cochrane Library, and SCOPUS (Appendix Table 1, available online). The reference lists of relevant systematic reviews and all included studies were also screened. In addition, Google Scholar was used to conduct a forward citation search of relevant systematic reviews and all included studies.

Studies were considered eligible for inclusion if they investigated and reported on exposure to resistance training and mortality within a healthy adult population of those aged ≥18 years and were either an RCT or a cohort study. Studies that were conducted in clinical populations (e.g., cancer survivors), nonhuman studies, studies not published in English, editorials, reviews, commentaries, conference abstracts, and letters were excluded.

### Study Selection

All studies identified by the search were imported into Covidence (Veritas Health Innovation, Melbourne, Australia), where duplicates were removed before screening. A total of 3 investigators (PS, TB, and KL) conducted the title and abstract screening independently against the eligibility criteria. Any conflicts were resolved by consensus between 2 investigators (PS and TB). Two investigators (PS and TB) then reviewed the full text of eligible studies against the eligibility criteria. Disagreements were resolved by discussion and consensus between the same 2 investigators. Where >1 published article had used the same or overlapping data to investigate the same outcome, we only included the study with the largest sample size.

### Risk of Bias

The 'Tool to Assess Risk of Bias in Cohort Studies' was used to assess the risk of bias in the cohort studies and was developed by the CLARITY Group at McMaster University in 2013. The risk of bias tool was used to assess the following: whether the exposed and nonexposed cohorts were drawn from the same population, measurement of the exposure; absence of the outcome at baseline; matching and/or adjustment for relevant confounders;

measurement of confounders; measurement of the outcome; loss to follow-up; and whether any cointerventions (i.e., coexposures) that may influence the outcome are similar in the exposed and nonexposed groups.[20] Researchers select from the range of response options provided for each question, including *Definitely yes* (low risk of bias), *Probably yes, Probably no*, and *Definitely no* (high risk of bias). The appraisal was completed independently by 2 reviewers (PS and TB), and any differences were resolved by consensus.

### Data Extraction

Data extraction was performed for all studies that met the inclusion criteria, using a predetermined data extraction pro forma in Microsoft Excel (version 1811, Microsoft Cooperation 2018) by 1 investigator (PS). The extraction template was trialed in 1 study by 1 investigator (PS); the other investigators (TB, KB, and KL) revised the template, and all the 4 investigators came to an agreement over the template used. The accuracy of the extracted data was independently reviewed by a second investigator (TB), and any disagreements or discrepancies were resolved by consensus.

The following general variables were extracted: author; year of publication; country; data set; and study population characteristics such as sample size, age, and sex. The details on exposure characteristics included details on date, type, duration, intensity, and/or frequency of resistance training and MVPA at baseline (and any follow-ups if applicable). The outcome measures included the date of the end of the follow-up, mean or median follow-up time, total person-years of follow-up in different categories of the exposure, all effect sizes (e.g., hazard ratios, ORs), and associated 95% CIs related to the association between resistance training and the risk of mortality (all-cause, CVD, cancer) and all effect sizes and associated 95% CIs related to the joint association between resistance training and MVPA with mortality risk.

### Meta-Analysis

For all-cause, CVD, and cancer mortality outcomes with risk estimates from 3 or more studies available, random-effects meta-analyses were conducted to estimate the association between (1) performing any amount of resistance training compared with performing no resistance training and (2) the highest levels of resistance training compared with the lowest levels of resistance training reported (highest versus lowest) and the outcome. Statistical heterogeneity between studies was tested using the Cochrane's *Q*-test and quantified by the $I^2$ statistic. Forest plots were used to visually display the summary effect size and individual results of the studies included in each meta-analysis. Publication bias was assessed with Egger's test and visual inspection of funnel plots.

A 1-stage random-effects dose–response meta-analysis using restricted cubic splines (with 3 knots placed at 10, 30, and 150 minutes, which roughly correspond with the 10th, 50th, and 90th percentiles of the distribution of dose values from the included studies) was performed to estimate the relationship between the volume of resistance training (i.e., minutes per week) and all-cause mortality and to investigate whether the dose−response relationship was nonlinear. Where applicable, the midpoint of each category of resistance training was used as the dose. If person-years were not reported for each category of resistance training, it was estimated by multiplying the number of persons in a specific exposure group and the mean follow-up years of the total study population. Stata (version 16; StataCorp, College Station, TX) was used for all analyses.

## RESULTS

The initial search identified 6,702 studies. After removal of duplicates (*n*=3,137) and initial title and abstract screening, 47 studies were included for full-text screening. Of these 47 studies, we excluded 9 that were conducted on clinical populations; 8 that did not have resistance training as an exposure; 7 that did not include any of the outcomes of interest; and 4 articles that were a review, editorial, or letter. A total of 9 further studies were excluded because of overlapping samples.[21-29] A total of 10 studies met the eligibility criteria for inclusion (Figure 1).[15-17,30-36]

### Study Characteristics

The characteristics of the included studies are shown in Appendix Table 3 (available online). All studies used a prospective cohort design. All studies were conducted in the U.S., except 1 study from the United Kingdom[15] and 1 study from Australia.[31] The length of follow-up ranged from 7 to 17 years, and the age range of the total participants was 18–85 years. A total of 8 of the studies included males and females in their study population, whereas 1 study only included females,[30] and 1 study only included males.[31]

A total of 7 of the 10 studies conducted 1 or more sensitivity analyses. A total of 5 studies conducted sensitivity analyses in which they excluded participants who died within 12–24 months of follow-up,[16,30,32-34] whereas 4 studies conducted sensitivity analyses in which they excluded those with previous CVD,[17,32] a previous cancer diagnoses,[17,33] or chronic conditions.[16] All the 7 studies reported that the results from sensitivity analyses were similar to the results from their main analyses.

### Assessment and Prevalence of Resistance Training

Resistance training was measured with self-reported questionnaires in all the included studies. There was large heterogeneity in the questions used to measure resistance training and the way resistance training was categorized (Appendix Table 3, available online) and also the terminology used to describe resistance training. For example, the term resistance training was used in 1 study,[32] weight lifting was used in 3 studies,[17,30,35] strength exercises was used in 1 study,[15] and muscle-strengthening activities or exercises to strengthen the muscles was used in 5 studies.[16,31,33,34,36] The proportion of participants reporting any amount of resistance training ranged from 9% to 27%.

### Risk of Bias

All the 10 included studies were found to have a higher risk or very high risk of bias in the way the exposure

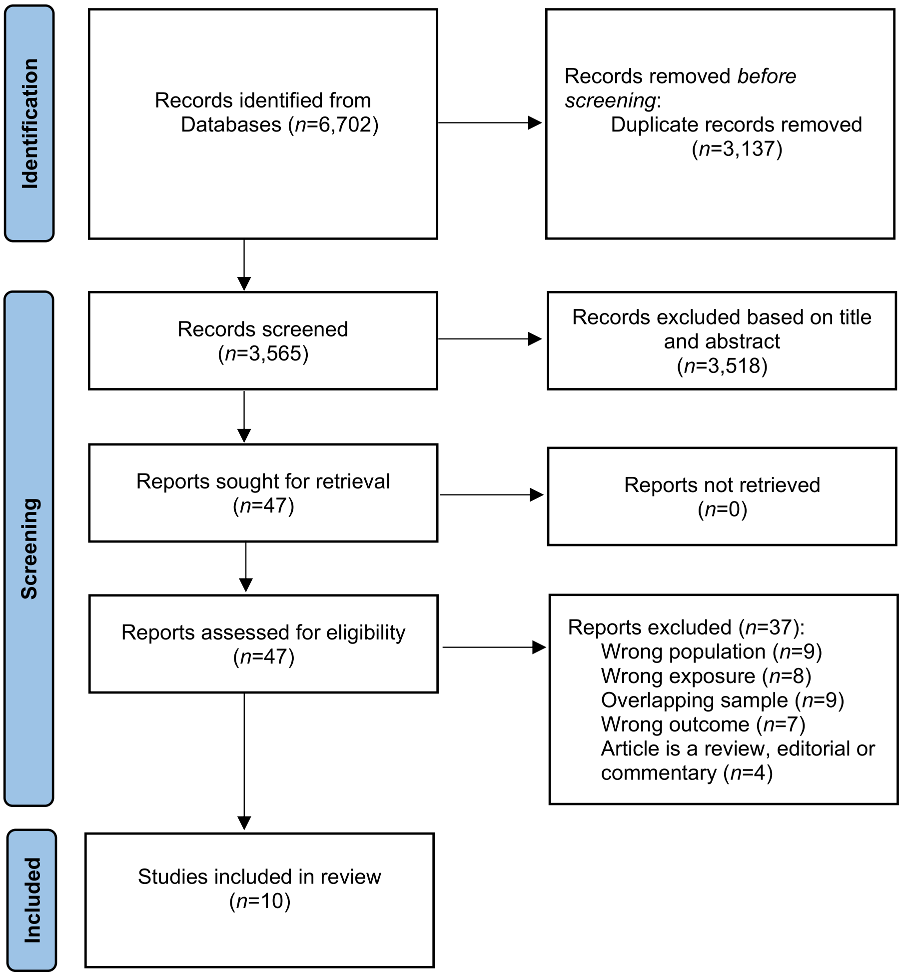


**Figure 1.** PRISMA flow diagram with details about the literature search, with the number of included and excluded studies at each stage, and with reasons for exclusion.

(resistance training) was measured because it was self-reported, was measured at only a single point in time, and/or did not report on the validity or reliability of the specific question used to assess resistance training (Appendix Table 2, available online). All other items on the risk of bias assessments were rated as having a very low or low risk of bias.

## All-Cause Mortality

Performing any amount of resistance training versus performing no resistance training lowered the risk of all-cause mortality by 15% (Summary RR of 6 studies=0.85; 95% CI=0.77, 0.94; $I^2$ =79.9%) (Table 1 and Figure 2). This association was attenuated and not statistically significant when comparing the highest level of resistance training with the lowest level of resistance training (RR of 7 studies=0.92; 95% CI=0.83, 1.01; $I^2$ =57.6%) (Table 1 and Appendix Figure 1, available online).

A total of 4 studies reported the required information to include in the dose−response meta-analysis of the association between minutes per week of resistance training and all-cause mortality.[15,30,32,34] A nonlinear, "U"-shaped relationship was observed in the analysis, with the risk of mortality decreasing and a maximum risk reduction of 26% observed at around 60 minutes per week of resistance training (RR=0.74; 95% CI=0.64, 0.86) (Figure 3 and Appendix Figures 2 and 3, available online). Mortality risk reductions diminished at higher volumes than 60 minutes per week of resistance training.

The joint effect of both resistance training and MVPA was analyzed in 3 studies.[15,16,30] When compared with mortality among those doing neither resistance training nor MVPA, all-cause mortality was reduced by 18% (RR=0.82; 95% CI=0.72, 0.93; $I^2$=73.4%) (Table 1 and Appendix Figure 4, available online) among those only performing resistance training, by 25% (RR=0.75; 95%

**Table 1.** Summary of Results From Meta-Analyses of Resistance Training and Mortality

| Meta-analysis | All-cause mortality | | | CVD mortality | | | Cancer mortality | | |
|---|---|---|---|---|---|---|---|---|---|
| | *n* | $I^2$, % | Summary, RR (95% CI) | *n* | $I^2$, % | Summary, RR (95% CI) | *n* | $I^2$, % | Summary, RR (95% CI) |
| RT | | | | | | | | | |
| Some versus none | 6 | 79.9 | 0.85 (0.77, 0.94) | 4 | 64.7 | 0.81 (0.61, 1.00) | 5 | 62.8 | 0.86 (0.78, 0.95) |
| Highest versus lowest | 7 | 57.6 | 0.92 (0.83, 1.01) | 6 | 35.2 | 0.90 (0.79, 1.02) | 6 | 46.8 | 0.87 (0.77, 0.99) |
| Joint association of RT and MVPA | | | | | | | | | |
| No RT and no MVPA | 3 | – | 1.00 (ref) | 3 | – | 1.00 (ref) | 3 | – | 1.00 (ref) |
| RT only | 3 | 73.4 | 0.82 (0.72, 0.93) | 3 | 0 | 0.82 (0.74, 0.91) | 3 | 11.1 | 0.84 (0.75, 0.94) |
| MVPA only | 3 | 88.0 | 0.75 (0.67, 0.84) | 3 | 65.2 | 0.71 (0.61, 0.81) | 3 | 90.3 | 0.89 (0.72, 1.10) |
| RT and MVPA | 3 | 57.5 | 0.60 (0.54, 0.66) | 3 | 61.0 | 0.54 (0.41, 0.70) | 3 | 84.8 | 0.72 (0.53, 0.98) |

CVD, cardiovascular disease; $I^2$, degree of heterogeneity; MVPA, moderate-to-vigorous physical activity; RT, resistance training.

CI=0.67, 0.84; $I^2$=88%) (Table 1) among those only performing MVPA, and by 40% (RR=0.60; 95% CI=0.54, 0.66; $I^2$=57.5%) (Table 1) among those performing both resistance training and MVPA.

## CVD Mortality

Performing any amount of resistance training versus performing no resistance training lowered the risk of CVD mortality by 19% (summary RR of 4 studies=0.81;

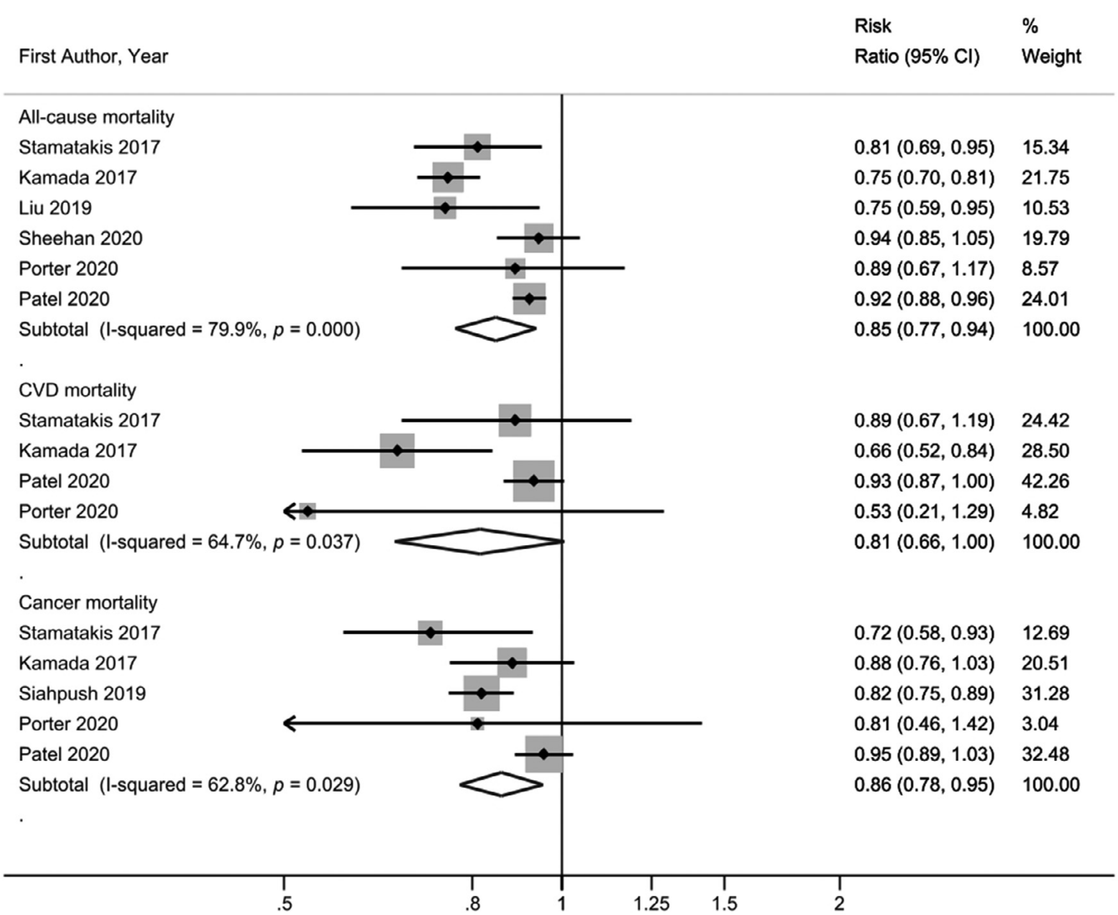


**Figure 2.** Meta-analysis of the associations between engaging in any resistance training versus engaging in no resistance training and the risk of all-cause, CVD, and cancer mortality.
CVD, cardiovascular disease.

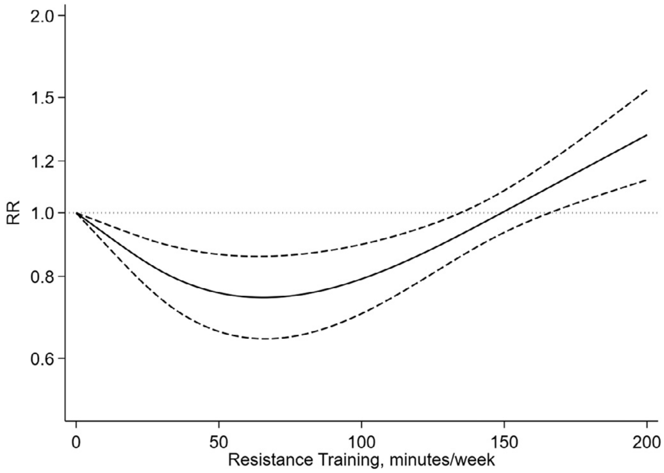


**Figure 3.** Dose−response meta-analysis of studies (*n*=4) investigating the duration of resistance training and the risk of all-cause mortality.

*Note*: The solid line represents the summary risk ratio, and the dashed lines represent the 95% CIs.

95% CI=0.66, 1.00; $I^2$=64.7%) (Table 1 and Figure 2). The association was attenuated and not statistically significant when comparing the highest level of resistance training with the lowest level of resistance training (RR of 6 studies=0.90; 95% CI=0.79, 1.02; $I^2$=35.2%) (Table 1 and Appendix Figure 1, available online).

The joint effect of resistance training and MVPA on CVD mortality was analyzed among 3 studies.[15,16,30] When compared with the risk of doing neither resistance training nor MVPA, the risk of CVD mortality was reduced by 18% by performing resistance training only (RR=0.82; 95% CI=0.74, 0.91; $I^2$=0%) (Table 1 and Appendix Figure 5, available online), by 29% by performing MVPA only (RR=0.71; 95% CI=0.61, 0.81; $I^2$=65.2%) (Table 1), and by 46% among those performing both resistance training and MVPA (RR=0.54; 95% CI=0.41, 0.70; $I^2$=61.0%) (Table 1).

### Cancer Mortality

Performing any amount of resistance training versus performing no resistance training lowered the risk of cancer mortality by 14% (summary RR of 5 studies=0.86; 95% CI=0.78, 0.95; $I^2$=62.8%) (Table 1 and Figure 2). Similarly, performing the highest level of resistance training compared with performing the lowest level of resistance training lowered the risk of cancer mortality by 13% (RR of 6 studies=0.87; 95% CI=0.77, 0.99; $I^2$=46.8%) (Table 1 and Appendix Figure 1, available online).

The joint effect of resistance training and MVPA on cancer mortality was analyzed among 3 studies.[15,16,30] When compared with the risk of performing neither resistance training nor MVPA, the risk of cancer mortality was reduced by 16% by performing resistance training only (RR=0.84; 95% CI=0.75, 0.94; $I^2$=11.1%) (Table 1 and Appendix Figure 6, available online), and no reduction in the risk of cancer mortality was observed by performing MVPA only (RR=0.89; 95% CI=0.72, 1.10; $I^2$=90.3%) (Table 1). However, cancer mortality risk reduced by 28% among those performing both resistance training and MVPA (RR=0.72; 95% CI=0.53, 0.98; $I^2$=84.8%) (Table 1).

### Publication Bias

The results of Egger tests and visual inspection of funnel plots indicated potential publication bias in the highest versus lowest meta-analysis for CVD mortality. There was no indication of potential publication bias in any of the other meta-analyses reported earlier (data not shown).

## DISCUSSION

In this systematic review and meta-analysis of 10 studies, resistance training was associated with a lower risk of all-cause mortality, cancer mortality, and CVD mortality. Compared with performing no resistance training, doing any resistance training lowered the risk of all-cause mortality by 15%, CVD mortality by 19%, and cancer mortality by 14%. The results of our dose−response meta-analysis suggested a possible "U"-shaped relationship between the duration of resistance training and the risk of all-cause mortality; however, because this analysis only included 4 studies, it should be viewed with caution. Our results also indicate that performing both resistance training and MVPA was associated with the greatest reduction in the risk of all-cause, cancer, and CVD mortality than performing either physical activity mode alone.

Consistent with the previous systematic review on this topic[14] our results indicate that resistance training is associated with a reduced risk of all-cause mortality. By including 9 new studies,[15-17,31-36] our review builds on previous research[14] and provides the strongest evidence to date that resistance training is also associated with a reduced risk of CVD mortality and cancer-specific mortality. Our results for cancer mortality are also consistent with a more recently published review,[19] which indicates that resistance training is associated with a reduced risk of cancer mortality.

Several different physiologic mechanisms could explain why resistance training is a protective factor against mortality. Clinical exercise studies have shown that resistance training has favorable associations with glucose and lipid metabolism,[7] regulating insulin sensitivity[37] and blood pressure.[38] Resistance training is also associated with improving lean muscle mass and strength[39] and the reduction of visceral fat,[40] all of which are associated with a lower risk of mortality.[41,42]

A novel finding was that the results of our dose−response meta-analysis showed a possible "U"-shaped relationship between the duration of resistance training and the risk of all-cause mortality. In particular, the largest mortality risk reduction (33%) was observed at 60 minutes of resistance training per week, and greater volumes than 60 minutes per week were associated with smaller or no mortality risk reductions. Given the small number of studies included, we urge caution in interpreting this finding. However, the results of the studies to date indicate that any potential mortality benefits gained by performing resistance training may diminish at higher volumes of resistance training. Previous clinical studies have shown that high volumes and intensity resistance training may also result in adverse effects on blood pressure, heart rate, and arterial compliance.[43,44] More research is needed to better understand the dose−response relationship between resistance training and mortality.

Data from public health surveillance have shown that almost 60% of U.S. adults report not engaging in any resistance training activity at all; however, only 25% of the adults report not engaging in any MVPA physical activity.[45] The discrepancy between the higher prevalence of MVPA activity and the prevalence of resistance training suggests that more emphasis could be placed on the health benefits of resistance training. Some of the key challenges faced when starting resistance training could be that, unlike MVPA, resistance training requires basic training and information, such as the correct form when doing squats, the muscles targeted by certain resistance training exercises, etc.[46] Another key factor for the low prevalence of resistance training could be the lack of resources or access to equipment (e.g., free weights, resistance bands, gym membership, etc.).[46] To address some of these challenges, public health strategies will need to focus on a multidisciplinary approach, which may include easy and affordable access to physical health/fitness instructors, affordable access to well-equipped spaces to perform resistance training activities (such as community gymnasium/fitness centers), and promotion of alternative forms of resistance training such as yoga and exercises that use one's body weight that can be performed at home.[45]

### Limitations

One of the key limitations of the literature on resistance training and the risk of mortality is the measurement of resistance training. Resistance training was self-reported in all the included studies, 8 of the 10 studies only had information about resistance training at a single point in time, and no studies reported on the validity or reliability of the item(s) used to measure resistance training specifically. It is currently not clear how accurately people can recall the time they spend performing resistance training levels or whether they report time at the gym rather than the exact duration of time spent engaged in resistance training activities. The studies included in this review also measured and reported the amount of resistance training in numerous different ways: some studies looked at resistance training in hours per week[17,30,32] whereas others measured resistance training in the frequency or number of sessions per week.[32,33] This meant that only 4 studies were included in the dose−response meta-analysis for all-cause mortality and limited our ability to conduct dose−response analyses for cancer mortality and CVD mortality. The heterogeneity in measurement of resistance training in the included studies is consistent with a recent review that examined the way resistance training exercise has been measured in public health surveillance studies.[47] More research is needed to identify the best/most valid method to measure resistance training to comprehensively understand the dose−response association between resistance training and mortality/other chronic disease outcomes. Because few studies have stratified by age and sex, it is also not clear whether the association between resistance training and mortality risk may differ depending on these important demographic factors.

## CONCLUSIONS

This systematic review and meta-analysis provides the strongest evidence to date that resistance training is associated with a reduced risk of all-cause mortality, CVD mortality, and cancer-specific mortality. These results, combined with the low prevalence of resistance training in the general population,[48] indicate that more emphasis could be placed on resistance training in health promotion campaigns aimed at increasing physical activity levels.

## CREDIT AUTHOR STATEMENT

Prathiyankara Shailendra: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing - original draft. Terry Boyle: Conceptualization, Methodology, Project administration, Supervision, Writing - review and editing. L.S. Katrina Li: Conceptualization, Methodology, Supervision, Writing - review and editing. Katherine L. Baldock: Conceptualization, Methodology, Supervision, Writing -

review and editing. Jason A. Bennie: Conceptualization, Methodology, Writing - review and editing.

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## SUPPLEMENTAL MATERIAL

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