Title: Daily steps as a public health metric for physical activity monitoring and promotion

Short Title: Daily Steps and Health

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Abstract (60/60 words)

This review summarizes the evidence on the number and intensity of steps associated with health benefits. For older adults, 6,000 to 8,000 daily steps is associated with substantial CVD and mortality benefits and taking more than 8,000 daily steps appears to be associated with additional benefit. For younger adults, 8,000 to 10,000 daily steps is associated with substantial mortality benefit.

Summary (15/20 words)

Summarizes the science on prospective associations of daily steps with mortality and CVD in adults.

Key points (116/150 words)

- Among older adults, taking at least 6,000 to 8,000 daily steps is associated with substantial CVD and mortality benefits. Older adults may get additional benefits beyond 8,000 daily steps.
- Among younger adults, taking at least 8,000 to 10,000 daily steps is associated with substantial mortality benefits.
- It remains unclear if step intensity (rate) matters beyond the total number of daily steps.
- Findings from this review include the most recent science on daily steps and health in more than 125,000 adults and may be informative in developing future physical activity guidelines.
- Including repeated measure longitudinal data, underrepresented groups, and a broader range of health outcomes may help strengthen the evidence base for step-based recommendations.

Key words (7/7 key words)

steps; physical activity; walking; exercise; guidelines; mortality; cardiovascular disease

INTRODUCTION

Step counts are a popular and practical method for measuring and promoting physical activity. Step counting devices are commonplace (1–3), making them accessible for people to track their steps. They also provide a straightforward metric for easy communication and can measure physical activity accrued throughout the day with intensities ranging from light to vigorous. Despite the practical advantages of step counts, data to support the development of step count goals complementing guidelines for moderate-to-vigorous intensity physical activity (4) has been limited. In 2018, the Physical Activity Guidelines Advisory Committee concluded the evidence was insufficient to establish a step guideline (5). The Committee highlighted the need for more studies on the daily step number, as well as the intensity needed for health benefits.

Since the Committee's report (5), research on the association between step counts and health has increased. Recent large-scale studies have investigated the prospective association between daily steps and risk for all-cause mortality and cardiovascular disease (CVD) (6–9). In a nationally-representative sample of US adults (≥40 years), for example, more daily steps were associated with progressively less risk in all-cause mortality which leveled off at 8,000 to 10,000 daily steps (10). A meta-analysis of 7 published and 8 unpublished studies (including 47,471 adults and 3,013 deaths) also showed the curvilinear association between daily steps and mortality depended on age. Higher step counts were associated with lower mortality risk among younger adults (<60 years), leveling at 8,000 to 10,000 daily steps, and among older adults (≥60 years) leveling at 6,000 to 8,000 daily steps (9). CVD risk among older adults leveled at 6,000 to 9,000 daily steps (8). Two other meta-analyses confirmed the nonlinear dose-response relation with CVD and mortality (6, 7). Among more than 110,000 adults in 12 published studies, there was progressively less risk up to about 8,800 daily steps for mortality and up to about 7,200 daily steps for CVD, although the findings were not reported by age (7).

Our review summarizes the data on the number and intensity of steps associated with health benefits among younger and older adults. Since our previous meta-analyses, (8, 9) recent studies, including findings from over 70,000 adults residing in the United Kingdom, (11, 12) provide important contributions to the science on steps and health. In total, four cohort studies (12–15) not included in the earlier meta-analyses more than double the number of participants and outcomes available, adds a substantial amount of new data on the association between steps and all-cause mortality and CVD. Here, we include these data in an updated meta-analysis to improve the robustness of the estimated association between steps, mortality, and CVD; In addition, we examine whether additional studies in different populations yield similar results and provide information for younger and for older adults. We examine results from a diverse group of studies on step intensity (rate) and health. Federal physical activity guidelines recommend moderate-to-vigorous intensity aerobic physical activity for substantial health benefit (4). It remains unclear, however, if step intensity matters beyond the total number of daily steps. We will also describe the current landscape of how daily steps are measured across different wearable devices. Our review addresses key questions about steps and health (5, 16) and can guide the development of future physical activity guidelines.

PROSPECTIVE COHORT STUDIES ON STEPS AND MORTALITY AND CVD

To summarize the current evidence, we updated our systematic review and meta-analyses on daily step count and its associations with all-cause mortality and CVD, building on our prior work (8, 9). A total of 21 studies on mortality and 12 on CVD were identified through a systematic search for prospective studies published until August 2024 that used device-measured steps and reported outcomes by quantiles. Of these, 17 studies were included in the mortality meta-analysis and 11 in the CVD meta-analysis. Pooled hazard ratios were estimated using random-effects models, stratified by age. Detailed explanation of our methods and results of sensitivity analyses by device type, fixed effects models and leave-one-out tests are included in the Supplement.

Table 1 summarizes all prospective cohort studies on steps and all-cause mortality (Table 1). Seventeen studies met inclusion criteria for the mortality analysis, encompassing over 127,000 adults with a median follow-up of 7.4 years. The overall median of the median daily steps was 6,439 steps per day, with younger adults (median [IQR]: 7803 [5377-10536] steps per day) walking significantly more than older adults (5649 [3686-8094] steps per day). A total of 5,778 deaths were reported, 4,654 deaths among older adults (8.5 per 1,000 participant years) and 1,124 deaths among younger adults (2.9 per 1,000 participant-years).

[Table 1: Characteristics of Cohort Studies on Steps per Day and All-Cause Mortality]

Table 2 summarizes all prospective cohort studies on steps and CVD (Table 2). For the meta-analyses, there were 11 studies including 109,033 participants (individual-level mean age 63.1 years, 59% females) with a median study follow-up time of 7.6 years (range 3.1 to 20 years) (Table 2). The overall median of the median daily steps was 5,602 (IQR: 3,660-8,173). A total of

5,625 CVD events were included, 4,358 events among the older adults (9.1 events per 1,000 participant-years) and 1,267 among the younger adults (3.5 events per 1,000 participant-years).

[Table 2: Characteristics of Cohort Studies on Steps per Day and Cardiovascular Disease]

DOSE RESPONSE ASSOCIATION OF DAILY STEPS AND HEALTH

To explore the shape of the association between daily steps and mortality and CVD outcomes, we modeled dose-response relationships using restricted cubic splines, stratified by age group (Figure 1). Taking more daily steps was associated with lower risk of all-cause and CVD, following a curvilinear dose-response pattern, which varied according to age. Among older adults, the range at which much of leveling occurred was 6,000 to 8,000 daily steps, although risk continued to decline above 8,000 daily steps for both outcomes. Among younger adults, taking 8,000 to 10,000 daily steps was associated with the lowest risk of mortality. We did not find significant associations for steps and CVD events among younger adults. We identified the hazard ratio at each median quartile of daily steps along the dose-response curve. Among older adults, higher daily step counts were associated with substantially lower risks of both mortality and CVD. Compared to those taking 2,840 steps per day (median of the lowest quartile), mortality risk was 42% lower at 5,216 steps, 53% lower at 7,117 steps, and 60% lower at 10,500 steps. CVD risk followed a similar pattern, with reductions of 36%, 44%, and 49% at these same step volumes. In younger adults, compared to 4,849 steps per day, mortality risk was 32% lower at 7,245 steps, 38% lower at 8,911 steps, and 35% lower at 11,482 steps.

[Figure 1: Dose-Response Association of Daily Steps with All-Cause Mortality and Fatal and Non-Fatal Cardiovascular Disease for the (a) Total Sample and (b) Older Adults and (c) Younger Adults]

We present a summary of the hazard ratios at each 1,000-step increment along the dose-response curve for all-cause mortality and CVD events (Figure 2). Our analysis indicated a dose-response similar to the established curvilinear association for moderate-to-vigorous physical activity with health (5). Notably, there was a steep decline in risk at the lower range of step counts.. Among older adults, compared to a reference group averaging 3,000 daily steps, those taking 4,000 steps had 21% less risk of mortality, and 37% less risk at 5,000 steps, and 46% less risk at 6,000 steps. Beyond 6,000 steps, the observed incremental benefit begins to level off but continues in a downward trend among older adults. Among older adults, compared to those taking 3,000 daily steps, those taking 7,000 steps had a 51% lower risk, 8,000 steps corresponded to a 53% lower risk, and 9,000 steps corresponded to a 55% lower risk. Similar associations were observed for cardiovascular risk among older adults. Among younger adults, compared to those taking 5,000 daily steps, individuals taking 6,000 daily steps had 16% lower risk of mortality, 28% lower at 7,000 steps, and 34% lower at 8,000 steps. After 8,000 steps, the benefits plateau, showing a 37% lower risk at 9,000 steps and a 36% lower risk at 10,000 steps.

[Figure 2. Dose-Response Association of Daily Steps with All Cause-Mortality and Cardiovascular Disease among Older and Younger Adults Indicating Hazard Ratios at 1,000 Daily Step Increments]

SUBSTANTIAL HEALTH BENEFIT

There are a variety of ways authors identify the number of steps offering substantial health benefit (Table 3), although there is currently no standard method. The term “substantial health benefit” is used by the Physical Activity Guidelines to describe a physical activity threshold where better health occurs (4). One common method identifies the point where the dose-response curve begins to “level”, where little added benefit is observed for risk of disease. In our meta-analysis, the dose-response curve for younger adults started to level at 8,000 to 10,000 daily steps, coinciding with 40% lower mortality risk. Among older adults, much of the leveling occurred at a range of 6,000 to 8,000 daily steps. Among older adults, there may be further benefit in going beyond 8,000 daily steps. We focus on a range of step counts rather than a single distinct value, as this acknowledges there is likely a range at which 'substantial health benefit' falls. In addition, a range also accounts for device variability in step estimates (30). Another common method is to examine improvements in daily steps, such as moving from the least active quartile to the next active quartile, or alternatively, as 1,000 daily step increments.

Our findings show, compared to older adults who took 3,000 daily steps, those who took 4,000 daily steps had 20% lower risk of mortality and CVD.

[Table 3: Published Studies of Daily Steps and Mortality Showing Criteria Used to Determine a Step Range or Value Associated with Substantial Mortality Benefit]

A comparison group serves as a point of reference, allowing estimate of a *relative* risk of disease. Many steps and health studies used a comparison group derived from their study sample. Study samples were diverse (e.g., device methodology, disease status, age) which makes it challenging to compare relative risks across single studies (Figure 3). Many studies used the first quartile as the referent group, with the median number of daily steps in these referent groups ranging from about 2,000 to 6,000 (Table 3). Our harmonized meta-analytic approach allowed us to summarize the health benefits from 17 studies of mortality and 11 studies of CVD using a common comparison group, the lowest study quartile. This method improves comparability by accounting for differences in populations, devices, and measurement protocols, and avoids inconsistencies that arise when using a fixed step threshold that may represent different percentiles across age groups—such as 2,000 steps reflecting the 25th percentile in older adults but only the 10th percentile in younger adults. Our interpretation of this meta-analysis shows the overall shape and inflection points of the dose-response curve remains consistent regardless of the exact reference step count used (Supplement Figure 8).

Many studies of steps and mortality or CVD (6, 7, 31) present a dose-response curve showing an early, steep decline in risk. The early, steep part of the curve is linear, making interpretation of a minimum step count challenging, as there is no absolute threshold at which the benefits begin (6–9). We, therefore, do not interpret the early, steep portion of the dose-response curve as an absolute minimum number of daily steps for health benefits, but rather as a starting point from which adults may wish to increase their daily steps.

[Figure 3. Three criteria to consider when interpreting health benefit from a dose-response curve of daily steps and all-cause mortality: An example from a meta-analysis of older adults.]

STEPPING INTENSITY

Figure 4 provides a qualitative summary of published studies examining the association between step intensity and both all-cause mortality and CVD. Due to substantial heterogeneity in how step intensity was defined—spanning 14 different metrics across step rate (e.g., steps/min), duration (e.g., minutes/day), and volume-specific intensities (e.g., brisk steps/day)—and in the statistical methods used, a meta-analysis was not feasible. Eight publications reported on the association between at least one step intensity variable and mortality (6 studies) or CVD (2 studies). Among the studies on mortality, four studies reported results with and without statistical adjustment for step volume, or total steps per day. Among the 4 studies (9, 10, 22, 23)with step intensity and mortality results with and without adjustment for step volume, 3 studies reported a significant association of higher stepping intensity associated with less mortality or CVD risk prior to adjusting for step volume. However, most of the associations were attenuated and non-significant after adjusting for step volume. Another study only reported results adjusting for step volume and found significant associations for all 7 step rate variables quantified (11). There were 2 studies on step rate and CVD events (8, 11). One study found no associations with or without adjustment for step volume (8), whereas the other showed associations with four of seven step rate metrics used after adjusting for total step volume (11).

[Figure 4: Summary of Observational Study Results on Associations of Step Intensity Metrics with All-Cause Mortality and Cardiovascular Disease When (a) Not Adjusting and (b) Adjusting for Total Daily Step Volume]

Taken together, these findings suggest that while higher step intensity may be associated with additional health benefits, its independent role beyond total daily steps is not yet fully understood. The attenuation of associations after adjusting for step volume points to the strong influence of overall daily step accumulation in associated with lower mortality and CVD risk. At the same time, some studies continued to show significant associations even after adjustment, indicating that step intensity could have a complementary role. Greater consistency in how step intensity is measured and analyzed may help clarify its potential contribution to health outcomes.

Describing the independent effect of step intensity (rate) on health is challenging for several reasons. There is no standard metric for step intensity. Eight studies of step intensity used 14 different metrics, making it difficult to summarize the findings. The variety of step intensity metrics may also reflect different constructs. For example, time spent at a step rate of 40 or 100 steps per minute may reflect typical walking speed, whereas metrics, such as the highest average step rate in 30- (peak 30) or 60-minutes (peak 60), may reflect physical capacity or cardiorespiratory fitness. A meta-analysis among four studies (18) found higher peak 30-minute step cadence was associated with lower all-cause mortality, however this was primarily influenced by one large study (31).It is also analytically challenging to separate the total number of steps from step intensity. People who walk faster take more steps and there is, therefore, a high correlation (>0.80) between step intensity and step number (18, 22).

Most step intensity metrics were developed in laboratories using treadmill protocols (32, 33) and may not fully translate to free-living conditions. For example, in the Women's Health Study, a prospective cohort study of older women, only 0.2% of a participant's day was spent at or above 100 steps per minute (22), one of the suggested thresholds for moderate-to-vigorous intensity stepping (34). Developing age-appropriate step intensity metrics representing free-living conditions could help answer questions about the potential added health benefits of walking briskly. Studies using experimental designs where participants are assigned to different walking speeds (keeping total steps constant) to test effects on intermediate health outcomes, like cardiovascular risk factors, may be useful in clarifying if walking speed provides additional health benefits beyond total steps.

STEP-COUNTING DEVICES

Step-counting devices tend to reliably (consistently) measure steps over time, but the validity (accuracy) of devices can vary. Daily step estimates can differ by 20% or more (30, 35, 36), presumably because devices are programmed with different step definitions and algorithms. Wear locations such as the waist, hip, or wrist can also influence step estimates (30, 36). The range in steps associated with health reported in publications may be caused, in part, to differences in the device manufacturer, wear location, and step algorithms applied in the study (36). Interpreting the absolute number of steps associated with lower mortality or CVD risk from studies using different types of monitors can be challenging. Considering this, our meta-analysis identified a *range* of steps associated with substantial health benefit for mortality and CVD.

Harmonizing step definitions and algorithms, including those from research and consumer devices, may help strengthen the evidence on the range of step counts and intensity levels needed for health benefits, enhancing future efforts to promote daily steps (37).

HEALTH ASSOCIATIONS OF MODERATE TO VIGOROUS PHYSICAL ACTIVITY AND DAILY STEPS

Step counts and physical activity behavior both appear to be health enhancing aerobic activities, with similar hazard ratios and dose-response curves. An analysis from The Women's Health Study compared moderate-to-vigorous physical activity and step counts measured by accelerometer. The findings showed both measures, when compared by quartiles, produced similar hazard ratios for all-cause mortality and CVD risk (38, 39). If the data support it, a physical activity guideline for steps could complement, not replace, the adult aerobic guideline based on time (≥150 mins/week) and intensity (moderate-to-vigorous intensity), allowing for greater flexibility in communicating physical activity options for health.

ADDRESSING LIMITATIONS OF PREVIOUS STUDIES

We added four new cohort studies to the meta-analysis, contributing data from over 80,000 adults to both the mortality and CVD outcomes. The inclusion of these studies did not substantially change our findings but improved the precision of the effect estimates, reinforcing the conclusions from our original meta-analysis. While there is consistent and substantial evidence linking step counts to all-cause mortality and CVD, important gaps remain for future research.

Our review reveals opportunities investigators may consider addressing limitations of previous studies on steps and health. Our analysis showed the range in steps associated with mortality and CVD was different among younger and older adults. Studies reporting findings by sex (9) and race/ethnicity (10, 18) show similar daily step amounts associated with health. Studies including participants with chronic conditions or from low-income countries are less common. Including populations infrequently studied can help address gaps related to generalizability. Participants with high step counts (e.g., >12,000 steps per day) are relatively few, limiting our ability to interpret associations between higher step volumes and mortality and CVD.

Most studies report daily steps during a single period. Physical activity behavior can change over time; therefore, studies investigating changes in daily steps and changes in intermediate risk factors may be informative. Although studies control for sociodemographic, lifestyle, and health status factors in our analyses, residual confounding and reverse causality might still be present. Very low step counts could reflect underlying health conditions or frailty, which may contribute to an increased risk of adverse events. Additionally, experimental designs where participants are assigned to different walking speeds (keeping total steps constant) may be useful in clarifying if walking speed provides additional health benefits beyond total steps.

Examining the dose-response relation between step counts and health beyond all-cause mortality and CVD can provide a holistic view of steps and health. Some studies suggest dementia (40), diabetes (41, 42), and cancer (11, 43, 44) may show a different dose-response pattern with steps. A recent meta-analysis studied a broad range of health outcomes—including type 2 diabetes, cancer, dementia, depressive symptoms, physical function, and falls (31). Although this meta-analysis included only 2 to 4 studies for most outcomes, it provides important initial insights, showing consistent beneficial associations across all outcomes despite variation in the shape of the dose-response curves. Notably, approximately 7,000 steps per day was associated with substantial lower risk in all outcomes compared to 2,000 steps (31).

The lack of association between step counts and CVD in younger adults in our current analysis may be due to the relatively few CVD events in this group, as CVD typically manifests later in life. However, intermediate CVD risk factors, such as blood pressure and glycemic control, are of particular interest in younger populations for early prevention, yet these factors remain less studied and may warrant further investigation.

Our findings align with a recent review identifying 7,000 steps per day as a threshold associated with meaningful lower risk with higher steps across a broad range of health outcomes in adults (18). Both studies emphasize the benefits of accumulating more steps, reinforcing step volume as a key health metric. The recent review also examined age-specific differences, finding varying inflection points and dose-response shapes by age group (31). However, direct comparisons between our study and this meta-analysis are limited due to differences in subgroup definitions and included studies. Previous meta-analyses have often grouped studies using broader age categories, such as mean age above or below 65 years. In contrast, our harmonized meta-analysis approach utilized non-overlapping age groups (<60 and ≥60 years) based on stratified data obtained directly from contributing studies. This approach allowed studies to be assigned to both age groups where appropriate, maximizing sample size and reducing age overlap while balancing study design variation. Our age-specific analysis incorporates a larger and more diverse set of studies—14 older and 10 younger for mortality, and 9 older and 6 younger for CVD. Understanding mechanisms behind these age differences, including roles of underlying health status and physical function, remains an important area for future research.

CONCLUSIONS

The science on the number of daily steps associated with substantial health benefits has increased. Taking more daily steps is associated with a curvilinear dose-response relation with CVD and all-cause mortality, which varied according to age. Among older adults, taking at least 6,000 to 8,000 daily steps is associated with substantial CVD and mortality benefits. Older adults may get additional benefits beyond 8,000 daily steps. Among younger adults, taking at least 8,000 to 10,000 daily steps is associated with substantial mortality benefits. Findings from this review may be informative in developing physical activity guidelines.

REFERENCES

1. Nagappan A, Krasniansky A, Knowles M. Patterns of Ownership and Usage of Wearable Devices in the United States, 2020-2022: Survey Study. *J Med Internet Res*. 2024;26:e56504.

2. Mobile Fact Sheet*Pew Research Center*. 2024; [cited 2025 May 23] Available from: https://www.pewresearch.org/internet/fact-sheet/mobile/.

3. Vogels EA. About one-in-five Americans use a smart watch or fitness tracker. *Pew Research Center*. 2020; [cited 2025 May 23] Available from: https://www.pewresearch.org/short-reads/2020/01/09/about-one-in-five-americans-use-a-smart-watch-or-fitness-tracker/.

4. Piercy KL, Troiano RP, Ballard RM, et al. The Physical Activity Guidelines for Americans. *JAMA*. 2018;320(19):2020.

5. 2018 Physical Activity Guidelines Advisory Committee. 2018 Physical Activity Guidelines Advisory Committee Scientific ReportU.S. Department of Health and Human Services; 2018.

6. Banach M, Lewek J, Surma S, et al. The association between daily step count and all-cause and cardiovascular mortality: a meta-analysis. *European Journal of Preventive Cardiology*. 2023;30(18):1975–85.

7. Stens NA, Bakker EA, Mañas A, et al. Relationship of Daily Step Counts to All-Cause Mortality and Cardiovascular Events. *Journal of the American College of Cardiology*. 2023;82(15):1483–94.

8. Paluch AE, Bajpai S, Ballin M, et al. Prospective Association of Daily Steps With Cardiovascular Disease: A Harmonized Meta-Analysis. *Circulation*. 2023;147(2):122–31.

9. Paluch AE, Bajpai S, Bassett DR, et al. Daily steps and all-cause mortality: a meta-analysis of 15 international cohorts. *The Lancet Public Health*. 2022;7(3):e219–28.

10. Saint-Maurice PF, Troiano RP, Bassett DR, et al. Association of Daily Step Count and Step Intensity With Mortality Among US Adults. *JAMA*. 2020;323(12):1151.

11. Del Pozo Cruz B, Ahmadi MN, Lee I-M, Stamatakis E. Prospective Associations of Daily Step Counts and Intensity With Cancer and Cardiovascular Disease Incidence and Mortality and All-Cause Mortality. *JAMA Intern Med*. 2022;182(11):1139.

12. Small SR, Chan S, Walmsley R, et al. Self-Supervised Machine Learning to Characterize Step Counts from Wrist-Worn Accelerometers in the UK Biobank. *Medicine & Science in Sports & Exercise*. 2024;56(10):1945–53.

13. LaMonte MJ, LaCroix AZ, Nguyen S, et al. Accelerometer-Measured Physical Activity, Sedentary Time, and Heart Failure Risk in Women Aged 63 to 99 Years. *JAMA Cardiol*. 2024;9(4):336.

14. Fretts AM, Siscovick DS, Malloy K, et al. Ambulatory Activity and Risk of Premature Mortality Among Young and Middle-aged American Indian Individuals. *JAMA Netw Open*. 2023;6(5):e2311476.

15. Watanabe D, Yoshida T, Watanabe Y, Yamada Y, Miyachi M, Kimura M. Dose–Response Relationships between Objectively Measured Daily Steps and Mortality among Frail and Nonfrail Older Adults. *Medicine & Science in Sports & Exercise*. 2023;55(6):1044–53.

16. Piercy KL, Vaux-Bjerke A, Polster M, et al. Call to Action: Contribute to the Development of the Third Edition of the Physical Activity Guidelines for Americans. *Transl J ACSM*. 2024;10(1).

17. Jefferis BJ, Parsons TJ, Sartini C, et al. Objectively measured physical activity, sedentary behaviour and all-cause mortality in older men: does volume of activity matter more than pattern of accumulation? *Br J Sports Med*. 2019;53(16):1013.

18. Paluch AE, Gabriel KP, Fulton JE, et al. Steps per Day and All-Cause Mortality in Middle-aged Adults in the Coronary Artery Risk Development in Young Adults Study. *JAMA Netw Open*. 2021;4(9):e2124516.

19. Yamamoto N, Miyazaki H, Shimada M, et al. Daily step count and all-cause mortality in a sample of Japanese elderly people: a cohort study. *BMC Public Health*. 2018;18(1).

20. Hansen BH, Dalene KE, Ekelund U, et al. Step by step: Association of device-measured daily steps with all-cause mortality—A prospective cohort Study. *Scandinavian Med Sci Sports*. 2020;30(9):1705–11.

21. Dwyer T, Pezic A, Sun C, et al. Objectively Measured Daily Steps and Subsequent Long Term All-Cause Mortality: The Tasped Prospective Cohort Study. *PLOS ONE*. 2015;10(11):e0141274.

22. Lee I-M, Shiroma EJ, Kamada M, Bassett DR, Matthews CE, Buring JE. Association of Step Volume and Intensity With All-Cause Mortality in Older Women. *JAMA Intern Med*. 2019;179(8):1105.

23. Mañas A, del Pozo Cruz B, Ekelund U, et al. Association of accelerometer-derived step volume and intensity with hospitalizations and mortality in older adults: A prospective cohort study. *Journal of Sport and Health Science*. 2022;11(5):578–85.

24. Fox KR, Ku P-W, Hillsdon M, et al. Objectively assessed physical activity and lower limb function and prospective associations with mortality and newly diagnosed disease in UK older adults: an OPAL four-year follow-up study. *Age and Ageing*. 2015;44(2):261–8.

25. Oftedal S, Holliday EG, Attia J, et al. Daily steps and diet, but not sleep, are related to mortality in older Australians. *Journal of Science and Medicine in Sport*. 2020;23(3):276–82.

26. Alver SK, Pan S, Mossavar-Rahmani Y, et al. Physical Activity, Cardiovascular Status, Mortality, and Prediabetes in Hispanic and Non-Hispanic Adults. *JAMA Netw Open*. 2024;7(6):e2415094.

27. Cochrane SK, Chen S, Fitzgerald JD, et al. Association of Accelerometry-Measured Physical Activity and Cardiovascular Events in Mobility-Limited Older Adults: The LIFE (Lifestyle Interventions and Independence for Elders) Study. *JAHA*. 2017;6(12)

28. Yates T, Haffner SM, Schulte PJ, et al. Association between change in daily ambulatory activity and cardiovascular events in people with impaired glucose tolerance (NAVIGATOR trial): a cohort analysis. *The Lancet*. 2014;383(9922):1059–66.

29. Pan S, Chen S, Fretts AM, Ali T. Associations of pedometer-measured ambulatory activity with incidence of atherosclerotic cardiovascular diseases: Strong heart family study. *Preventive Medicine*. 2023;177:107781.

30. Toth L, Paluch AE, Bassett DR, et al. Comparative Analysis of ActiGraph Step Counting Methods in Adults: A Systematic Literature Review and Meta-Analysis. *Medicine & Science in Sports & Exercise*. 2024;56(1):53–62.

31. Ding D, Nguyen B, Nau T, et al. Daily steps and health outcomes in adults: a systematic review and dose-response meta-analysis. *The Lancet Public Health*. 2025;10(8):e668–81.

32. Tudor-Locke C, Ducharme SW, Aguiar EJ, et al. Walking cadence (steps/min) and intensity in 41 to 60-year-old adults: the CADENCE-adults study. *Int J Behav Nutr Phys Act*. 2020;17(1).

33. Tudor-Locke C, Mora-Gonzalez J, Ducharme SW, et al. Walking cadence (steps/min) and intensity in 61–85-year-old adults: the CADENCE-Adults study. *Int J Behav Nutr Phys Act*. 2021;18(1)

34. Tudor-Locke C, Camhi S, Troiano R. A Catalog of Rules, Variables, and Definitions Applied to Accelerometer Data in the National Health and Nutrition Examination Survey, 2003–2006. *Prev Chronic Dis*. 2012; Available from: http://www.cdc.gov/pcd/issues/2012/11_0332.htm. doi:10.5888/pcd9.110332.

35. Toth LP, Park S, Springer CM, Feyerabend MD, Steeves JA, Bassett DR. Video-Recorded Validation of Wearable Step Counters under Free-living Conditions. *Medicine & Science in Sports & Exercise*. 2018;50(6):1315–22.

36. Bassett DR, Toth LP, LaMunion SR, Crouter SE. Step Counting: A Review of Measurement Considerations and Health-Related Applications. *Sports Med*. 2017;47(7):1303–15.

37. Anaya G, Pettee Gabriel K, St-Onge M, et al. Optimal Instruments for Measurement of Dietary Intake, Physical Activity, and Sleep Among Adults in Population-Based Studies: Report of a National Heart, Lung, and Blood Institute Workshop. *JAHA*. 2024; Available from: https://www.ahajournals.org/doi/10.1161/JAHA.124.035818. doi:10.1161/jaha.124.035818.

38. Hamaya R, Shiroma EJ, Moore CC, Buring JE, Evenson KR, Lee I-M. Time- vs Step-Based Physical Activity Metrics for Health. *JAMA Intern Med*. 2024;184(7):718.

39. Moore CC, Cuthbertson CC, Sotres-Alvarez D, et al. Step-Based Metrics and Translations of Physical Activity Guidelines among Adults in the HCHS/SOL. *Medicine & Science in Sports & Exercise*. 2023;55(8):1423–33.

40. Del Pozo Cruz B, Ahmadi M, Naismith SL, Stamatakis E. Association of Daily Step Count and Intensity With Incident Dementia in 78 430 Adults Living in the UK. *JAMA Neurol*. 2022;79(10):1059.

41. Cuthbertson CC, Moore CC, Sotres-Alvarez D, et al. Associations of steps per day and step intensity with the risk of diabetes: the Hispanic Community Health Study / Study of Latinos (HCHS/SOL). *Int J Behav Nutr Phys Act*. 2022;19(1)

42. Yates T, Davies MJ, Haffner SM, et al. Physical activity as a determinant of fasting and 2-h post-challenge glucose: a prospective cohort analysis of the NAVIGATOR trial. *Diabet Med*. 2015;32(8):1090–6.

43. Cuthbertson CC, Evenson KR, Wen F, et al. Associations of steps per day and step intensity with the risk of cancer: Findings from the Women's Health Accelerometry Collaboration cohort. *Preventive Medicine*. 2024;186:108070.

44. Shreves AH, Small SR, Travis RC, Matthews CE, Doherty A. Dose-response of accelerometer-measured physical activity, step count, and cancer risk in the UK Biobank: a prospective cohort analysis. *The Lancet*. 2023;402:S83.

Figure 1. Dose-Response Association of Daily Steps with All-Cause Mortality and Fatal and Non-Fatal Cardiovascular Disease Events for the (a) Total Sample and (b) Older Adults and (c) Younger Adults.

Reference set at the median of age-specific lowest quartile. Splines with knots set at 25th, 50th, and 75th percentile. Model adjusted for demographics, lifestyle, medical conditions, medications, and self-rated health. Dotted vertical lines indicate the ranges at which there is an inflection point where most of the leveling of the curve occurs indicating 'substantial' health benefit.

Figure 2. Dose-Response Association of Daily Steps with All Cause-Mortality and Cardiovascular Disease among Older and Younger Adults Indicating Hazard Ratios at 1,000 Daily Step Increments.

Model adjusted for demographics, lifestyle, medical conditions, medications, and self-rated health. Reference set at the median of age-specific lowest quartile rounded to the nearest 1000th, older adults' reference is 3,000 steps/day and younger adults' reference is 5,000 steps/day. Spline curve knots set at 25th, 50th, and 75th percentile. Y-axis is a log-scale. Labeled on the curves are the corresponding hazard ratios every 1,000 steps/day in comparison to the reference group. Blue shading indicates all-cause mortality. Red shading indicates cardiovascular disease.

Figure 3. Three criteria to consider when interpreting health benefit from a dose-response curve of daily steps and all-cause mortality: An example from a meta-analysis of older adults.

Several criteria can be used to interpret the daily step count associated with health benefit. 1) Comparison group: Benefits are often expressed relative to a comparison group. We set our comparison group (referent) at the median of the age-specific lowest quartile (rounded to the nearest 1000th). 2) Incremental benefit: Health benefit can be assessed in step increments, such as by each additional 1,000 steps, particularly at ranges along the steep early slope from 3,000 to 6000 daily steps. Our analysis showed health benefits with incremental increases in steps, especially among the least active participants. 3) Substantial benefit: Substantial health benefit may be considered where the dose-response curve begins to level. In our mortality meta-analysis of older adults, leveling occurred at approximately 6,000-8,000 daily steps for older adults, with potential benefit beyond 8,000 daily steps.

Figure 4. Summary of Observational Study Results on Associations of Step Intensity Metrics with All-Cause Mortality and CVD Events when (a) Not Adjusting and (b) Adjusting for Total Daily Step Volume.

spm = steps per minute. MVPA = moderate-to-vigorous physical activity. For each study, Green indicates a statistically significant association was found with step metric and health outcome; Gray indicates a statistically significant association was not found with step metric and health outcome.

Stepping Rate Metrics

- *Peak 1, 30, and 60 minutes represent the average cadence (steps/min) during the highest, not necessarily consecutive, 1, 30, or 60 minutes of ambulatory activity accumulated per day, averaged across all days.*
- *Max 5 is the maximum average cadence (steps/min) over any consecutive 5-minute period, averaged across all days.*
- *Total spm is the mean cadence (steps/min) across the entire day, averaged across all days.*
- *Bout ≥60 spm is the mean cadence (steps/min) during extended bouts (≥2 consecutive minutes) at ≥60 steps/min, averaged across all days.*

Stepping Duration Metrics

- *Time spent stepping at cadences of ≥40 and ≥100 steps/min is expressed as the average duration (minutes/day) at those cadences, averaged across all days.*

Stepping Number Metrics

- *The number of steps at <40 and ≥40 spm are the mean number of steps/day at cadences <40 and ≥40 steps per minute, averaged across all days.*
- *Light, Moderate, MVPA and Vigorous are the number of steps per day at light (<100 steps/minute), moderate (100-129 steps/minute), MVPA (≥100 steps/minute), and vigorous (≥130 steps/minute) cadences, averaged across all days.*

Table. 1 Characteristics of Cohort Studies on Steps per Day and All-Cause Mortality									
Cohort	**Country**	**Study Entry**	**Step Device (wear location)**	**N**	**Age, years, mean (S.D.)**	**Female (%)**	**Steps/d, Median [IQR], or Mean ± SD**	**Mean Years follow-up**	**No. of Deaths**
Studies from Steps for Health Collaborative publication[9]									
Activity and Function in the Elderly in Ulm (ActiFE)	Germany	2009-2010	ActivPAL (thigh)	1240	75.4 (6.5)	43%	7438 [5438-9702]	8.2	367
Atherosclerosis Risk in Communities Study (ARIC)	U.S.	2016-2017	ActiGraph GT3X (waist)	452	78.4 (4.7)	59%	3065 [2083-4453]	2.9	25
British Regional Heart Study (BRHS) [17]	United Kingdom	2010-2012	ActiGraph GT3X (waist)	1397	78.4 (4.6)	0%	4413 [2854-9826]	4.7	240
Cancer Prevention Study-3 (CPS-3)	U.S.	2015	ActiGraph GT3X (waist)	720	52.7 (10.0)	59%	7208 [5578-9269]	3.5	6
Coronary Artery Risk Development in Young Adults (CARDIA) [18]	U.S.	2005-2006	ActiGraph 7164 (waist)	2110	45.2 (3.6)	57%	9146 [7307-11162]	10.2	72
Framingham Heart Study (FHS)	U.S.	2008-2014	Actical (waist)	4548	55.3 (13.9)	54%	6752 [4643-9290]	7.1	157
Healthy Ageing Initiative	Sweden	2012-2018	ActiGraph GT3X (waist)	3793	70.4 (0.1)	51%	6832 [4927-8890]	4.3	138
Jackson Heart Study (JHS)	U.S.	2000	Yamax SW200 (waist)	401	60.2 (9.8)	61%	5213 [3738-7707]	13.5	87
National Health and Nutrition Examination Survey(NHANES)[10]	U.S.	2005-2006	ActiGraph 7164 (waist)	2382	56.9	50%	8465 [5721-11037]	10.0	517
Nateglinide and Valsartan in Impaired Glucose Tolerance Outcomes Research (NAVIGATOR)	40 Countries	2002-2004	Accusplit AE120 (waist)	7271	63.7 (6.9)	51%	5666 [3434-9139]	6.3	471
Niigata Elderly Study (NES) [19]	Japan	1999	Yamax – EC100 (waist)	416	71 (0)	45%	6115 [4495-7974]	9.8	76
Norwegian National Physical Activity Surveillance 1 (NNPAS1) [20]	Norway	2008-2009	ActiGraph GT1M (waist)	3043	49.9 (14.9)	53%	7784 [6045-9760]	8.9	122
Tasped Pooled Cohort Study (Tasped) [21]	Australia	2000	Yamax SW200 and Omrom-HJ (waist)	2576	58.7 (13.2)	52%	8936 [6102-12492]	11.1	219
Women's Health Study (WHS) [22]	U.S.	2011	ActiGraph GT3X (waist)	16741	72.0 (5.7)	100%	5094 [3610-6927]	4.3	504
New Cohort Study Additions to Meta-Analysis Results									
Kyoto–Kameoka Study [15]	Japan	2013	Panasonic EW-NK52 (waist)	4165	72.3 (5.4)	49%	4192 ± 2395	3.4	113
Strong Heart Family Study [14]	U.S.	2001-2003	Accusplit AE120 (waist)	2204	41.0 (16.8)	60%	5841 ± 3902	17.0	449

UK Biobank [12]	United Kingdom	2013-2015	Axivity AX3 (wrist)	73554	61.5 (7.9)	55%	9175 [6966-11786]	7.9	2215
Total included in meta-analysis results		**1999-2018**	**11 Devices (1 on wrist, 10 on waist)**	**127013**	**62.3**	**59%**	**6439 [4080-8768]**	**7.4**	**5778**
Other Cohort Studies Identified in Systematic Review, but not included in meta-analysis									
Toledo Study for Healthy Aging [23]	Spain	2021	ActiGraph wGT3X-BT (waist)	768	78.8 (4.9)	58%	5835 ± 3445	5.7	89
Project OPAL* [24]	United Kingdom	2007-2008	ActiGraph GT1M (waist)	213	70+	48%	4183 [3196-5170]	4.2	33
Hunter Community Study [25]	Australia	2005-2008	Digiwalker SW-200 (waist)	1731	65.4 (7.1)	49%	6898 ± 2969	9.5	204
Hispanic Community Health Study/Study of Latinos (HCHS/SOL) [26]	U.S.	2008-2011	Actical (waist)	9456	38.3 (13.9)	60%	Not reported	7.8	170

*Project OPAL steps is the midpoint and range of the middle tertile group.

Table 2. Characteristics of Cohort Studies on Steps per Day and Cardiovascular Disease

	Country	Study Entry	Step Device (wear location)	n	Age, years, mean(S.D.)	Female (%)	Steps/d, Median [IQR]	Mean Years of follow-up	No. of CVD Events
Studies from Steps for Health Collaborative publication[8]									
British Regional Heart Study (BRHS) [17]	United Kingdom	2010-2012	ActiGraph GT3X (waist)	1172	78.4 (4.6)	0%	4572 [2848 - 6296]	4.6	122
Lifestyle Interventions and Independence For Elders (LIFE) [27]	U.S.	2010-2013	ActiGraph GT3X (waist)	1341	78.7 (5.2)	67%	2415 [1627 - 3353]	3.1	202
Nateglinide and Valsartan in Impaired Glucose Tolerance Outcomes Research (NAVIGATOR) [28]	40 Countries	2002-2004	Accusplit AE120 (waist)	7271	63.7 (6.9)	51%	5662 [3435 - 8563]	6.3	730
Atherosclerosis Risk in Communities Study (ARIC)	U.S.	2016-2017	ActiGraph GT3X (waist)	452	78.4 (4.7)	59%	3065 [2083 - 4454]	2.8	34
Coronary Artery Risk Development in Young Adults (CARDIA)	U.S.	2005-2006	ActiGraph 7164 (waist)	2085	45.2 (3.6)	57%	9164 [7324 - 11163]	10.7	71
Framingham Heart Study (FHS)	U.S.	2008-2014	Actical (waist)	4223	55.3 (13.9)	54%	6906 [4809 - 9419]	7.0	151
Healthy Ageing Initiative (HAI)	Sweden	2012-2018	ActiGraph GT3X (waist)	3207	70.4 (0.1)	51%	6967 [5032 - 8991]	3.2	139
Jackson Heart Study (JHS)	U.S.	2000	Yamax SW200 (waist)	401	60.2 (9.8)	61%	4748 [2847 - 7284]	12.6	74
New Cohort Study Additions to Meta-Analysis Results									
UK Biobank [12]	United Kingdom	2013-2015	Axivity AX3 (wrist)	80437	61.9 (7.8)	58.5%	9,146 [6,918 - 11,734]	7.6	3395
Objective Physical Activity and Cardiovascular Health (OPACH) [13]	U.S.	2012-2014	ActiGraph GT3X (waist)	5952	78.6 (6.8)	100%	3133 [2303 - 4547]	7.5	406*HF only
Strong Heart Family Study [29]	U.S.	2001-2003	Accusplit AE120 (waist)	2492	40 (14.7)	62%	4925 [3010 - 7282]	20	301 *CHD only
TOTAL included in meta-analysis results		**2000-2018**	**6 devices (1 on wrist, 5 on waist)**	**109033**	**63.1**	**59.3%**	**5602 [3660 - 8173]**	**7.6**	**5625**
Other Cohort Studies Identified in Systematic Review, but not included in meta-analysis									
Hispanic Community Health Study/Study of Latinos (HCHS/SOL) [26]	U.S.	2008-2011	Actical (waist)	9456	38.3 (13.9)	60%	Not reported	7.8	91

Table 3: Published Studies of Daily Steps and Mortality Showing Criteria Used to Determine a Step Range or Value Associated with Substantial Mortality Benefit

Study name	Age range (years)	Device (wear location)	Reference group definition	Reference group daily steps (mean or median)	Range or value where daily step leveling* occurred	Hazard ratio associated with daily step leveling*
Studies Including Younger adults						
Strong Heart Family Study [14]	14 to 65	Accusplit AE120 (waist)	Lowest quartile	< 3,010 (mean ~1,930)	7,500	0.65
TASPED Pooled Cohort Study [21]	18 to 86	Yamax SW200 and Omron-HJ (waist)	Linear association	None (linear association)	Linear association	Not applicable
Coronary Artery Risk Development in Young Adults [18]	35 to 52	ActiGraph 7164 (waist)	<7,000 steps	5,837	10,000	0.45
UK Biobank [12]	40 to 79	Axivity AX3 (wrist)	Lowest quintile	<6,430 (mean ~5,000)	10,000	0.64
National Health and Nutrition Examination Survey [10]	40 to 80	ActiGraph 7164 (waist)	10th percentile	4,000	10,000 to 12,000	0.35
Steps for Health Collaborative [9]	40 to 60	Multiple devices	Lowest quartile	4,846	8,000 to 10,000	0.51
Norwegian National Physical Activity Surveillance 1 [20]	40 to 85	ActiGraph GT1M (waist)	Lowest quartile	4,600	8,000 to 9,000	0.43
Hunter Community Study [25]	55 to 85	Digiwalker SW-200 (waist)	Linear association	None (linear association)	Linear association	Not applicable
Studies Including *only* Older adults						
Steps for Health Collaborative [9]	60+	Multiple devices	Lowest quartile	2,841	6,000 to 8,000	0.43
Women's Health Study [22]	62 to 89	ActiGraph GT3X (waist)	Lowest quartile	2,718	7,500	0.42
Kyoto–Kameoka Study [15]	65+	Panasonic EW-NK52 (waist)	Lowest quartile	1,786	5,000 to 7,000	0.39
Toledo Study for Healthy Aging [23]	65+	ActiGraph wGT3X-BT (waist)	Linear association	None (linear association)	Linear association	Not applicable
Project Opal [24]	70+	ActiGraph GT1M (waist)	Lowest quartile	<3,196	Not reported	Not applicable
Niigata Elderly Study [19]	all 71	Yamax EC100 (waist)	Lowest quartile	3,394	Not reported	Not applicable
British Regional Heart Study [17]	72 to 91	ActiGraph GT3X (waist)	Lowest quartile	1,895	Not reported	Not applicable

*Leveling indicates the range or value of the step-mortality dose-response curve where the curve begins to level and substantial mortality benefit occurs.
Studies including younger adults are cohorts including adults 18+ years. Studies including only older adults, specifically focused on older adults 60+ years