Invited State-Of-The-Art Review

Physical activity, sedentary time and health – a narrative review with new insights

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ABSTRACT

Physical activity and sedentary time are associated with multiple health outcomes, and benefits also extend to those living with chronic conditions. These observations are primarily based on data from studies in which self-reported data assessed physical activity. Recent data where physical activity and sedentary time are measured with devices suggest that the dose-response association between device-measured physical activity and risk of incident diseases and mortality is greater and observed at lower levels of physical activity than indicated by self-reported data.

KEY POINTS

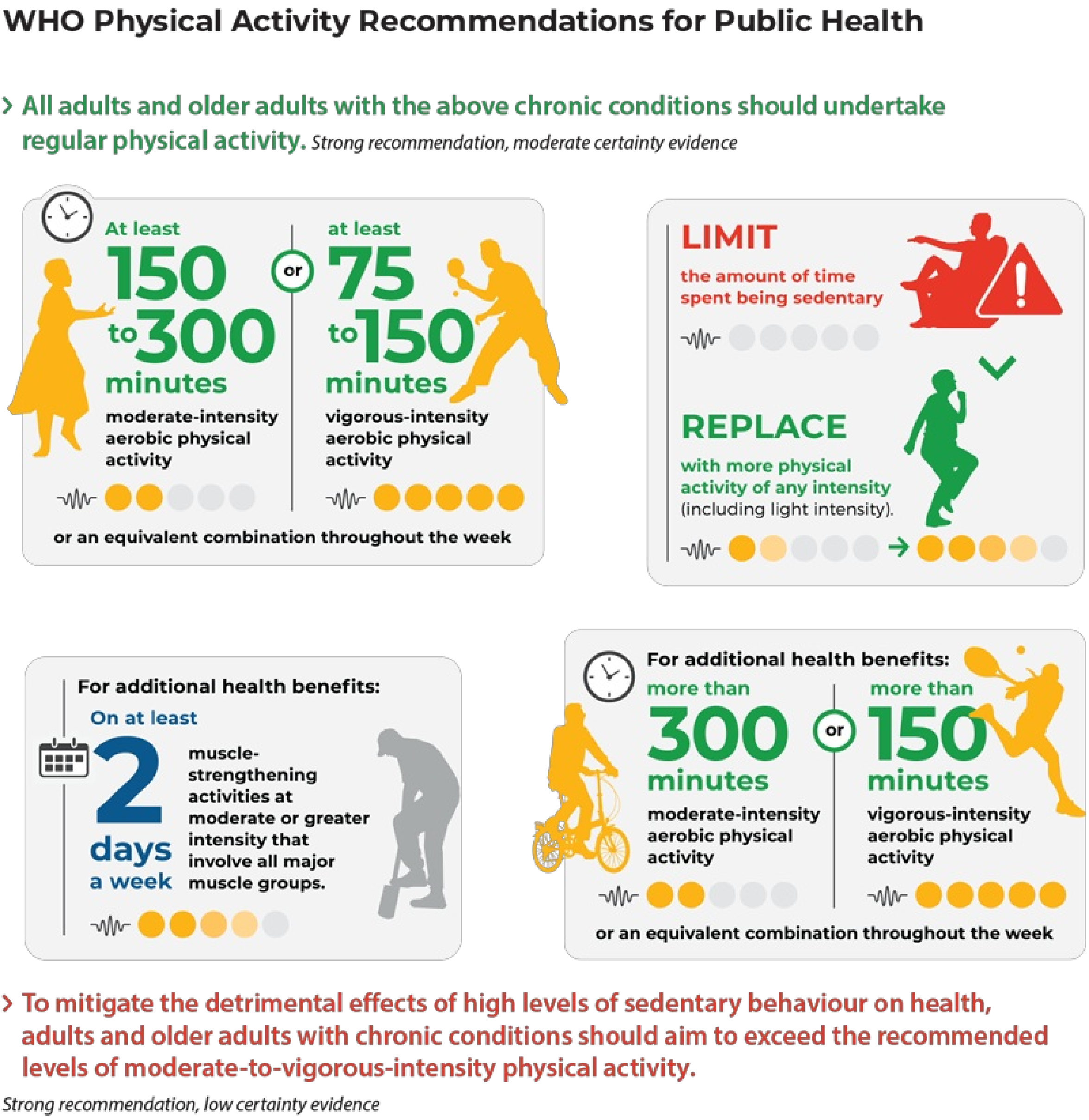
- Device-measured total physical activity, including the number of daily steps, is associated with a lower risk of morbidity and mortality in a dose-response fashion.
- Higher amounts of device-measured daily physical activity at all intensities (light, moderate and vigorous) lower the mortality risk.
- The mortality risk is substantially greater and observed at lower levels of physical activity when measured by devices than when derived from self-reported physical activity data.
- Physical activity of at least moderate intensity appears to offset the detrimental association between sedentary time and mortality.

Recent evidence based on self-report data suggest that approximately 30% of the global adult population is physically inactive, with an even greater proportion of inactive individuals in Western societies [1]. Additionally, physical inactivity may be responsible for 6-10% of major non-communicable diseases (NCDs) and up to 7% of premature mortality globally [2]. The benefits of physical activity (PA) extend also to those living with chronic conditions (i.e. secondary and tertiary prevention).

The contemporary understanding of the dose-response relationships between PA and risk for mortality suggests that the risk is substantially lower in active than in inactive individuals, defined by the World Health Organization (WHO) as less than 150 minutes of moderate-to-vigorous weekly PA (MVPA). Still, benefits are observed at levels below the WHO recommended level [3]. Recently, sedentary behaviours such as prolonged sitting have emerged as a risk factor for NCDs and premature mortality [3]. Consequently, the PA recommendations from the WHO now include recommendations on both PA and sedentary time (**Figure 1**).

However, these recommendations are almost entirely based on observational studies assessing PA and sedentary time based on self-reported data. Unfortunately, self-reports are prone to misclassification biases, such as recall and social desirability biases, which may result in over-estimating PA and underestimating daily sedentary time by almost two hours [5, 6].

FIGURE 1 Summary of the 2020 WHO physical activity and sedentary guidelines. The figure was adapted from WHO guidelines on physical activity and sedentary behaviour. Geneva: World Health Organization, 2020 [4]. Licence: https://creativecommons.org/licenses/by-nc-sa/3.0/igo/.



Here, we review new evidence that has emerged in recent years on device-measured population levels of PA and associations between PA, sedentary time and health outcomes. We discuss the evidence in terms of levels and trends, magnitude of dose-response associations and optimal dosing of PA intensity. Furthermore, we discuss whether PA can mitigate the detrimental associations between sedentary time and health outcomes.

Population levels, patterns and trends

So far, relatively few countries (approximately ten high-income countries) have implemented device-based measures of PA in the surveillance of nationally representative, population-based samples of the adult population. Cross-country comparisons of PA or sedentary time are, unfortunately, comprised by different monitor brands, data collection procedures, wear protocols and data processing protocols (algorithms) used across studies. Further, analysing time trends for the proportion of adults meeting PA recommendations is complicated by changes in international recommendations. Thus, the previous WHO recommendation from 2010 recommended a total of at least 150 minutes of MVPA weekly in bouts lasting a minimum of ten minutes. In contrast, the new recommendation from 2020, while maintaining the recommendation of 150 minutes of MVPA as the minimum, stipulates that time in MVPA does not need to be accumulated in bouts lasting a minimum of ten minutes [3].

The Norwegian National Physical Activity Survey (NNPAS) is one of few surveillance systems globally that collects data using devices (accelerometry). It has been conducted since 2008-2009, incorporating three waves of data in adults aged 18-80 years [7]. In general, the results from the latest survey conducted in 2021-2022 suggest that men spend somewhat more time in MVPA than women but also spend more time sedentary. On average, men accumulate about 44 minutes and women about 39 minutes in MVPA daily. Time spent in MVPA appears stable between 20 and 64 years of age but declines in those older than 65 years, especially time spent during vigorous intensity PA. A clear socioeconomic gradient is observed for PA and sedentary time. The highest socio-economic group spent 11 more minutes of MVPA daily than the lowest socio-economic group. Interestingly, when data from 2008 and 2014 are analysed according to the new PA recommendations, the proportion of adults meeting the 150 minutes of MVPA recommendation has increased by six percentage points from 67% in 2008 to 73% in 2022 [7].

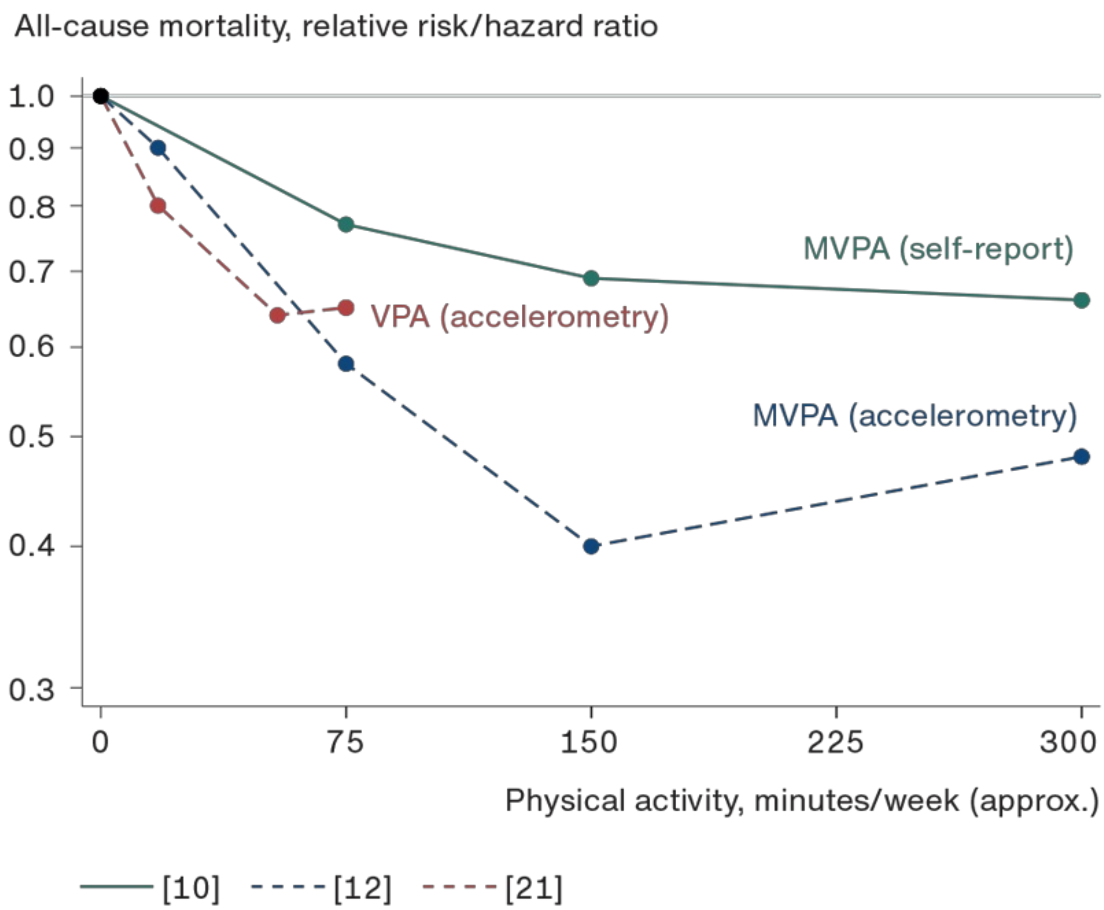
In Denmark, a nationally representative survey of the adult population was conducted in 2007-2008 (n = 224) and repeated in a larger sample in 2011-2012 (n = 1,515) [8]. The survey included men and women aged 18 years to 75 years and pedometers assessed PA during seven consecutive days. The number of steps declined by 446 steps per day from 8,788 steps per day in 2007-2008 to 8,341 steps per day in 2011-2012 (p = 0.08). Fewer steps among women primarily explained the decline. However, the number of daily steps was similar to that observed in the NNPAS (8,223 steps per day) and higher than comparable estimated data from Sweden (7,451 steps per day) [9].

Dose-response associations with health outcomes

Data from systematic reviews [10] and large pooled cohort studies [11] assessing leisure-time PA by self-report are consistent. First, the shape of the relationship between PA and mortality risk is non-linear and inverse. Second, the greatest improvement in mortality risk is observed when comparing those reporting no leisure-time PA with individuals being 'somewhat active' or insufficiently active, i.e.. less active than stipulated in the PA recommendations. Third, the maximal risk reduction for mortality, defined as the nadir of the dose-response association curve, is observed at PA levels substantially higher than the current PA recommendations and equates to an approximately 30% lower risk [10, 11].

Results from device-based measurements of PA associated with mortality risk extend the observations obtained with self-report. A harmonised meta-analysis of eight prospective cohort studies examined associations between total and intensity-specific PA with risk for all-cause mortality [12]. The harmonisation of PA data facilitated direct comparison of PA data between studies, which was impossible before. Total PA, regardless of intensity, was associated with a lower mortality risk. Furthermore, mortality risk was approximately 65% lower at the nadir of the dose-response curve than in the reference group (least active quartile). To put this into context, this activity level was lower than that observed in Norwegian men and women [7]. Thus, these results suggest substantially greater maximal risk reductions, which were observed at a lower level of PA than indicated by self-report data. As the nadir was at or below the activity level measured in nationally representative samples, it follows that these benefits are attainable for a very large population segment (**Figure 2**).

FIGURE 2 Dose-response association comparing moderate-to-vigorous intensity physical activity (MVPA) from self-reported activities (green line) and accelerometry (dashed blue line) by risk for mortality. The dashed red line shows the dose-response association between vigorous-intensity physical activity and risk for mortality. The magnitude of risk reduction is about twice as high when MVPA is assessed by accelerometry as with self-report for the same amount of MVPA. The figure is reproduced with permission from Ekelund et al. [13].



Total PA can also be defined as the total number of steps accumulated throughout the day. The number of steps is a simple measure and is easily understood by the general public. Furthermore, monitoring steps is feasible owing to the widespread use of smartwatches and mobile phones. However, the WHO Expert Committee on PA Recommendations concluded in 2020 that recommendations on the number of total steps and stepping rate were not feasible due to insufficient data [3].

On average, adults in Denmark and Norway accumulate more than 8,000 daily steps (see above); which is lower than the commonly accepted recommendation of 10,000 steps per day. However, this recommendation is not rooted in scientific evidence [14]. A harmonised meta-analysis of 15 cohort studies from Asia, Australia, Europe and North America showed a non-linear, dose-response association between daily steps and risk for mortality. The results suggested that the optimal number of steps for lowering mortality risk by approximately 40% to 50% was 6,000-8,000 daily steps and 8,000-10,000 steps per day in those older and younger than 60 years [15]. The total number of steps was also related to a lower risk of fatal and non-fatal cardiovascular events in those older than 60 years although not observed in other groups [16]. Another (non-harmonised) systematic review also observed an inverse, non-linear dose-response association between total daily steps and risk for mortality [17]. The risk for mortality was approximately 55% lower in those who accumulated 6,000 to 7,000 daily steps (Quartile 2 and 3) than in the reference group (Quartile 1, 3,900 daily steps). In conjunction, the data seem to indicate that the optimal number of daily steps for maximal mortality risk reduction is lower than 10,000 steps.

In research, steps are measured using research-grade accelerometers or pedometers with a defined wear location (e.g. wrist or waist). This differs from the public use of step-counters usually assessed by a smartwatch (which uses a proprietary algorithm) on the wrist or a mobile phone, which may not be worn all day or be worn differently by various population groups. Thus, a difference may exist between steps measured in a research setting and those measured by the public. This translational gap needs to be taken into account when new recommendations based on daily steps are formulated. The gap may also pose challenges for health professionals when recommending PA for preventive purposes. Rather than recommending a specific number of daily steps, it may be appropriate to recommend 500-step increases up to a minimum threshold of 8,000 daily steps.

Optimal dosing – light, moderate and vigorous intensity

Is light-intensity physical activity sufficient?

The optimal combination of light, moderate and vigorous-intensity PA for optimal health remains unclear. From a public health perspective, it is unlikely that all individuals can or are willing to increase their PA levels to comply with the WHO recommendations of at least 150 minutes of moderate-intensity activity per week [3]. Indeed, this intensity may be too hard for older or unfit people. Thus, increasing total PA by incorporating light-intensity activity into everyday life may be a feasible option. Light-intensity activity includes activities performed at an intensity below 3 METs (**Figure 3**) and includes activities such as light gardening, slow walking (< 3.6 km/h) and general household activities. Results from a harmonised meta-analysis of more than 36,000 middle-aged and older men and women (mean age 62.6 years) suggested a 40% lower risk for all-cause mortality when comparing the second quartile, who accumulated about 260 minutes per day in light-intensity activity with the first quartile (reference), accumulating about 200 minutes at this intensity level [12]. This suggests that a substantial amount of light-intensity activity is needed to lower the risk.

FIGURE 3 Absolute intensity categories and their corresponding metabolic equivalents (MET; multiples of resting energy expenditure) and examples of types of activities that correspond to the intensity categories. Cadence corresponding to light (< 100 steps/minute), moderate (101-130 steps/minute) and vigorous intensity (> 130 steps/minute) is included for comparison. Approximate relative intensity levels as percentages of maximal aerobic capacity (VO_{2max}) and maximal heart rate (HR_{max}) are shown at the bottom of the figure.

Absolute intensity categories

Sleep (< 1 MET)	Sedentary (1-1.5 METs)	Light (1.5-3 METs)	Moderate (3.1-6 METs)	Vigorous (6-9 METs)	Very Vigorous (> 9.1 METs)
		(3.5 km/h)	(5-6 km/h) (16 km/h)	(8 km/h) (> 18 km/h)	(> 10 km/h)
Cadence (steps/minute)		< 100	100-130	> 130	

Approximate relative intensity

$\%VO_{2max}$	< 25	25-44	45-59	60-84	> 84
$\%HR_{max}$	< 30	30-49	50-59	70-89	> 89

VO_{2max} = maximal aerobic capacity; HR_{max} = maximal heart rate

Moderate-to-vigorous intensity physical activity – the cornerstone of recommendations

Participating in MVPA is the cornerstone of the PA recommendations and is consistently associated with health benefits. Moderate-intensity PA refers to activity that requires an energy expenditure of 3-6 METs (Figure 3). Meta-analysis of the association between device-measured time spent in MVPA and risk for mortality suggests that the risk is reduced by approximately 50% for those accumulating a median of about 38 minutes per day (most active 25%) compared with the least active (median = 1.5 minutes MVPA per day) [12]. The second quarter (median = 6 minutes of MVPA per day) reduced the risk by 30-35% compared with the least active reference group. Maximal risk reductions for light intensity and MVPA are equivalent to almost twice the magnitude of risk reduction compared with that observed when PA is self-reported. Furthermore, risk reduction is also observed at substantially lower MVPA levels than were self-reported (Figure 2).

The UK Biobank study includes about 100,000 participants with device-measured PA with continuous follow-ups for clinical endpoints. The study has been instrumental to our understanding of the associations between different intensities of PA and risk for incident disease and mortality. The risk of incident cardiovascular disease (CVD) and CVD mortality was almost linear and similar in magnitude for total, MVPA and vigorous-intensity PA (VPA), and approximately 50% lower in the top quartile than in the least active quartile (reference) [18]. The linear dose-response association observed is opposite to the findings from other studies examining the dose-response association between device-measured PA and the risk of major clinical outcomes [12, 19]. The differences between studies may be explained by different placements of the activity monitor. The UK Biobank (UKBB) employed a dominant wrist placement, whereas others have opted for a waist placement [12, 19]. Placing the monitor on the wrist may have advantages in terms of compliance, whereas this placement may also pick up activities due to rapid arm movements that might not be of an intensity defined as at least moderate. Thus, some noise may be more present when data from wrist-worn accelerometers are associated with outcomes. Indeed, wrist accelerometry appears to record almost twice as many steps as waist accelerometry when the monitors are worn simultaneously [20].

How little vigorous-intensity physical activity is enough?

Vigorous intensity activity (> 6 METs), defined as activities that increase breathing and heart rate substantially (Figure 3), is considered to have twice the benefits of MVPA. This is exemplified in the 2020 WHO physical recommendations, where the minimum of 150 minutes of MVPA may be substituted for 75 minutes of vigorous-intensity activity or an equivalent combination of the two. This 2:1 relationship has been challenged by recent studies where time spent in vigorous-intensity activity was measured by accelerometry. For example, a non-linear dose-response association between VPA and risk of mortality suggested an 'optimal dose' (defined as the nadir of the dose-response curve) of approximately 55 minutes of VPA weekly, equivalent to 30% lower risk [21]. Similarly, non-linear dose-response associations were observed for cancer mortality, CVD and cancer incidence, whereas the association between VPA and CVD mortality were more linear without a clear threshold [21]. Interestingly, most VPA was performed in short bouts lasting less than three minutes.

Another UKBB study examined a specific concept of VPA in individuals who categorised themselves as 'non-exercisers'. The concept was labelled vigorous-intensity lifestyle PA (VILPA) and assumed to capture VPA outside regular exercise. A near-linear dose-response association between VILPA and risk of mortality was observed [22]. A median VILPA of 4.4 minutes per day was associated with an approximate 30% lower risk for all-cause, cancer and CVD mortality. So far, the current evidence on the health benefits obtained by participating in VPA is derived from the UKBB. Replication in additional studies, preferably using different wear locations, consensus-based activity classification algorithms, and more diverse and representative samples, will advance our knowledge about potential additional health benefits from participating in higher-intensity PA. This knowledge is important to inform future PA recommendations as to whether a smaller amount of VPA is required for health benefits compared with the current recommended level of at least 75 minutes per week.

Too much sedentary time – is it harmful?

Earlier systematic reviews concluded that prolonged sitting is associated with a higher risk for all-cause CVD and cancer mortality, and incident CVD, cancer and type 2 diabetes, independently of MVPA [23]. For example, the hazard was 24% higher for all-cause mortality when comparing the high to the low sedentary time groups. This observation was challenged by a harmonised meta-analysis of more than one million participants, which concluded that high levels of self-reported PA eliminated the association between sitting time and risk for all-cause, CVD and cancer mortality [24]. The top quartile of PA (i.e. ~ 250,000 participants) reported 60-70 minutes of MVPA per day. This group had no increased risk for mortality despite more than eight hours of sitting. This observation was confirmed in more recent cohort studies using device-measured PA.

For example, in joint association analyses combining device-measured MVPA and sedentary time, high MVPA (35 daily minutes of MVPA) was not associated with risk for mortality in any of the sedentary groups. In contrast, among those with low MVPA time (the lowest third) who accumulated 2-3 daily minutes of MVPA, sedentary time was associated with a 65% to 263% higher risk of death [24]. A similar study adopting an individual participant data approach observed that individuals whose activity level was in line with the recommendations had no increased risk regardless of the time spent sedentary. In contrast, more than 12 hours of sedentary time was associated with higher mortality risks among those who did not meet current PA recommendations [25].

Thus, the notion that sedentary time and sitting time are associated with a higher risk for mortality independently of MVPA was refuted when PA and sedentary time were modelled into combined analyses. In fact, the most recent data [25] indicate that participating in PA levels that align with the current PA recommendations appears to offset the detrimental association between sedentary time and risk of mortality. If replicated, these observations may have implications for future recommendations.

Concluding remarks

The availability of device-measured PA has produced advances in epidemiological evidence. There are, however, reasons to believe that the association between PA and mortality may still be underestimated by most observational studies because PA is usually measured only at baseline. Evidence suggests that the association may be stronger based on repeated PA measures [26]. Additionally, as this narrative review suggests, improvements in device-measured PA further strengthened the association between PA and health outcomes owing to reduced measurement error of the exposure variable (i.e. PA), which tends to bias the association towards the null.

In summary, emerging studies suggest that a more robust association may exist between PA and risk of morbidity and mortality, as well as a lower risk reduction threshold than for self-reported PA. Furthermore, the number of daily steps an indicator of overall PA is strongly associated with a lower risk of morbidity and mortality. High-intensity PA performed a few minutes daily may be associated with substantial risk reductions. However, the shape of the dose-response curve between different intensities of PA and risk for mortality remains unclear. Furthermore, the shape and magnitude of associations between device-measured PA and sedentary time with other important health outcomes, including type 2 diabetes, certain cancers and mental health, are lacking.

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