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SYSTEMATIC REVIEW

Health Benefits of Light-Intensity Physical Activity: A Systematic Review of Accelerometer Data of the National Health and Nutrition Examination Survey (NHANES)

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Abstract

Background The health effects of light-intensity physical activity (PA) are not well known today.

Objective We conducted a systematic review to assess the association of accelerometer-measured light-intensity PA with modifiable health outcomes in adults and older adults.

Methods A systematic literature search up to March 2016 was performed in the PubMed, EMBASE, Web of Science and Google Scholar electronic databases, without language limitations, for studies of modifiable health outcomes in adults and older adults in the National Health and Nutrition Examination Survey accelerometer dataset.

Results Overall, 37 cross-sectional studies and three longitudinal studies were included in the analysis, with considerable variation observed between the studies with regard to their operationalization of light-intensity PA. Light-intensity PA was found to be beneficially associated with obesity, markers of lipid and glucose metabolism, and mortality. Few data were available on musculoskeletal outcomes and results were mixed.

Conclusions Observational evidence that light-intensity PA can confer health benefits is accumulating. Currently inactive or insufficiently active people should be encouraged to engage in PA of any intensity. If longitudinal and intervention studies corroborate our findings, the revision of PA recommendations to include light-intensity activities, at least for currently inactive populations, might be warranted.

Key Points

Current physical activity (PA) recommendations advise on PA of at least moderate intensity.

Accumulating evidence suggests that PA of light intensity might be beneficial for cardiometabolic health and might reduce overall mortality risk.

Inclusion of light-intensity PA in PA recommendations for currently inactive populations might be warranted.

1 Introduction

Regular physical activity (PA) is one of the major modifiable risk factors for cardiovascular, metabolic and cancerous diseases and chronic conditions, as well as premature mortality [1]. National and international PA recommendations with a public health focus inform about the type, amount and intensity of PA judged to be necessary to maintain and improve health in the general population. A considerable part of the scientific database underlying these guidelines is made up of epidemiological studies, typically with a large number of participants, long follow-up periods, and hard clinical endpoints such as chronic disease (as opposed to risk factors) [2]. Epidemiological studies have, until very recently, relied mainly on self-reported PA. Cost effective and relatively easy to use, self-report is characterized by limited reliability and validity [3]. Since people tend to be able to recall PA of moderate to high intensity

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much more accurately than that of lower intensity, this method seems much less appropriate to capture PA in the lower intensity range [2, 4], implying that we are unsure about the possible health effects of light-intensity physical activity (LIPA) [the intensity range between sedentary behavior (SB) and moderate intensity, i.e. activities with 1.5–2.9 metabolic equivalents (METs)] rather than the fact that we can dismiss such effects [2]. Accordingly, current guidelines recommend regular PA of moderate to vigorous intensity (MVPA), providing no guidance on activities in the low-intensity range [5].

Wearable motion sensors such as accelerometers allow the accurate differentiation of a wide range of PA intensities with a relatively small burden on participants. Furthermore, technological advances have made accelerometers affordable and easy to use in large, population-based studies. Although studies using device-based measurements of PA suggest that people spend considerable time in light-intensity activities, little is known about the possible health effects of this behavior [6]. The concurrent availability of device-based PA data and health outcomes in epidemiological studies presents a new opportunity to study the possible health effects of PA across the entire intensity continuum.

The National Health and Nutrition Examination Survey (NHANES) assesses the health and nutritional status of the civilian, non-institutionalized population in the US, examining a nationally representative sample of approximately 5000 individuals [7]. The NHANES database provides a large dataset of device-based PA behavior and biomedical data using identical assessment methods and standards.

We performed a systematic review of the associations between device-based LIPA and modifiable health outcomes in adults and older adults in the NHANES, with the aim of providing further evidence for or against the promotion of LIPA in public health.

2 Methods

2.1 The National Health and Nutrition Examination Survey (NHANES)

The NHANES combines interviews including demographic, socioeconomic, dietary, and health-related questions and physical examinations, taking medical, dental and physiological measurements, and performing laboratory tests. Since the 2003/2004 wave, PA has also been device-based assessed using the ActiGraph model 7164 accelerometer (ActiGraph, LLC, Pensacola, FL, USA) [8]. This model is a uniaxial motion sensor that measures vertical acceleration, and accelerations are transformed into activity count values. The higher the acceleration, the higher the activity count. Activity counts are recorded in a 1-min time interval (epoch), thus activity counts are reported as counts per minute (cpm). Activities can be classified into light-, moderate-, and vigorous-intensity PA using validated cpm cut-off points [9]. NHANES participants were invited to wear the device on a flexible elastic waist belt over the right hip for 7 consecutive days at all times while awake, except for water-based activities such as swimming and showering.

2.2 Search Strategy

The present systematic review was prepared according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [10, 11]. A systematic literature search of the PubMed, EMBASE, Web of Science, and Google Scholar electronic databases was performed by two independent researchers (EF and TE) between January and March 2016, without language limitations. We adapted the search strategy used in a previous review [12] and included the term 'light activity'. Thus, key terms for the PubMed search were 'activity monitor' or 'ActiGraph', or the wild card term 'acceleromet*', in addition to 'NHANES' or 'National Health and Nutrition Examination Survey' and 'light activity' and 'NHANES'. For the EMBASE search, 'light intensity physical activity and NHANES' was used; for the Google Scholar search, 'light intensity AND physical activity AND NHANES' was used; and for the Web of Science search, 'light intensity physical activity AND NHANES' was used. Studies published between 2007 (release of the data of the NHANES 2003/2004 wave) and March 2016 were considered. We also performed hand searching in the reference citations of identified articles.

2.3 Study Selection

To be included in our analysis, studies had to (1) define and operationalize device-based LIPA (an intensity range between SB and moderate intensity); (2) report on the association between LIPA and a modifiable health outcome in a cross-sectional or longitudinal design; (3) include adults and older adults (≥18 years of age); (4) use data from the NHANES; and (5) be published in a peer-reviewed journal. Exclusion criteria were (1) studies reporting the prevalence of LIPA but no association with a modifiable health outcome; (2) studies in which analysis was based on total activity count; (3) studies in children or youth; and (4) studies other than NHANES. Study selection was performed independently and in duplicate by two researchers (EF and TE), and differences in opinion relating to inclusion and exclusion criteria were discussed until consensus was reached.

2.4 Data Extraction

We extracted the following descriptive information from the included studies into a preformatted spreadsheet: primary and secondary outcomes; covariates included in statistical models; sample size and characteristics of study participants, including age, sex distribution and other characteristics; NHANES wave; exposure measurement, including operationalization of LIPA, wear time per day and number of valid days required for inclusion; statistical methods used; major findings; study quality; authors; and year of publication.

2.5 Assessment of Study Quality

We studied the literature relating to reporting and quality assessment tools for observational studies [13–16] and found that because of, for example, missing items on accelerometry, no existing quality-assessment tool was ideally suited for the purposes of our review. For this reason, we developed a list of items to assess the quality of the studies included. Domains were identified based on a systematic review of assessment tools [14], and specific items were formulated based on Ariëns et al. [17] and Cliff et al. [18].

For each study, information on study quality was extracted by two reviewers (EF and TE), and differences in this assessment were discussed until consensus was attained. Study quality was determined by answers to the questions listed in Table 1. Items were coded as 'present' (1) or 'absent/unclear' (0). A cut-off value of 50% of the total possible points has previously been used to distinguish high- or moderate-quality studies from low-quality studies [17]. Since we applied a 12-item checklist, we further subdivided the upper 50% range into two. Accordingly, studies scoring 10 points and above were classified as high quality, those scoring 9–6 points were classified as moderate quality, and those scoring below 6 points were classified as low quality.

3 Results

3.1 Characteristics of the Included Studies

The literature review yielded 12,533 articles. After applying inclusion and exclusion criteria, 40 studies were included in the analysis (Fig. 1), of which 37 were cross-sectional [19–55] and 3 were longitudinal [56–58]. The cross-sectional studies examined the association of LIPA with a modifiable health outcome, and the three longitudinal studies examined the association of LIPA with mortality.

The characteristics of the included cross-sectional and longitudinal studies are summarized in Tables 2 and 3, respectively. Sample sizes varied widely across both the cross-sectional (n = 103–6796) and longitudinal studies (n = 3029–5575) depending on inclusion and exclusion criteria and research questions. Five studies analyzed only data from the 2003/2004 wave, 7 studies analyzed only data from the 2005/2006 wave, and 28 studies analyzed only data from the 2003/2004 and 2005/2006 waves. Sixteen studies reported on the general adult population, 14 studies reported on adults with chronic diseases, 9 studies reported on older adults with different age definitions, and 1 study reported on a special adult population (pregnant women). The lower limit of LIPA was defined as 100 cpm in all but two studies; Camhi and colleagues used 760 cpm [20] and Song et al. [55] used

Table 1 Assessment of study quality

1. Was the study purpose clearly stated?
2. Were eligibility criteria, and the sources and methods of selection of participants clearly defined?
3. Were all outcomes, exposures, predictors, potential confounders, and effect modifiers clearly defined using standardized methods of acceptable quality?
4. Was exposure measurement carried out using standardized methods and with acceptable quality (e.g. number of valid days)?
5. Were all statistical methods, including those used to control for confounding and to examine subgroups and interactions, appropriate?
6. Were methods dealing with missing data appropriate?
7. Was choice of confounders adjusted for, and, in case of subgroup analysis, definition of subgroups appropriate?
8. Were unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g. 95% confidence interval) given?
9. Were results adjusted for sedentary behavior?
10. Were results adjusted for moderate–vigorous physical activity?
11. Were estimates of relative risk translated into absolute risk for a meaningful time period?
12. Were study limitations clearly stated?

Items were coded as 'present' (1) or 'absent/unclear' (0). Studies scoring 10 points and above were classified as high, those scoring 9–6 points were classified as moderate, and those below 6 points were classified as low quality

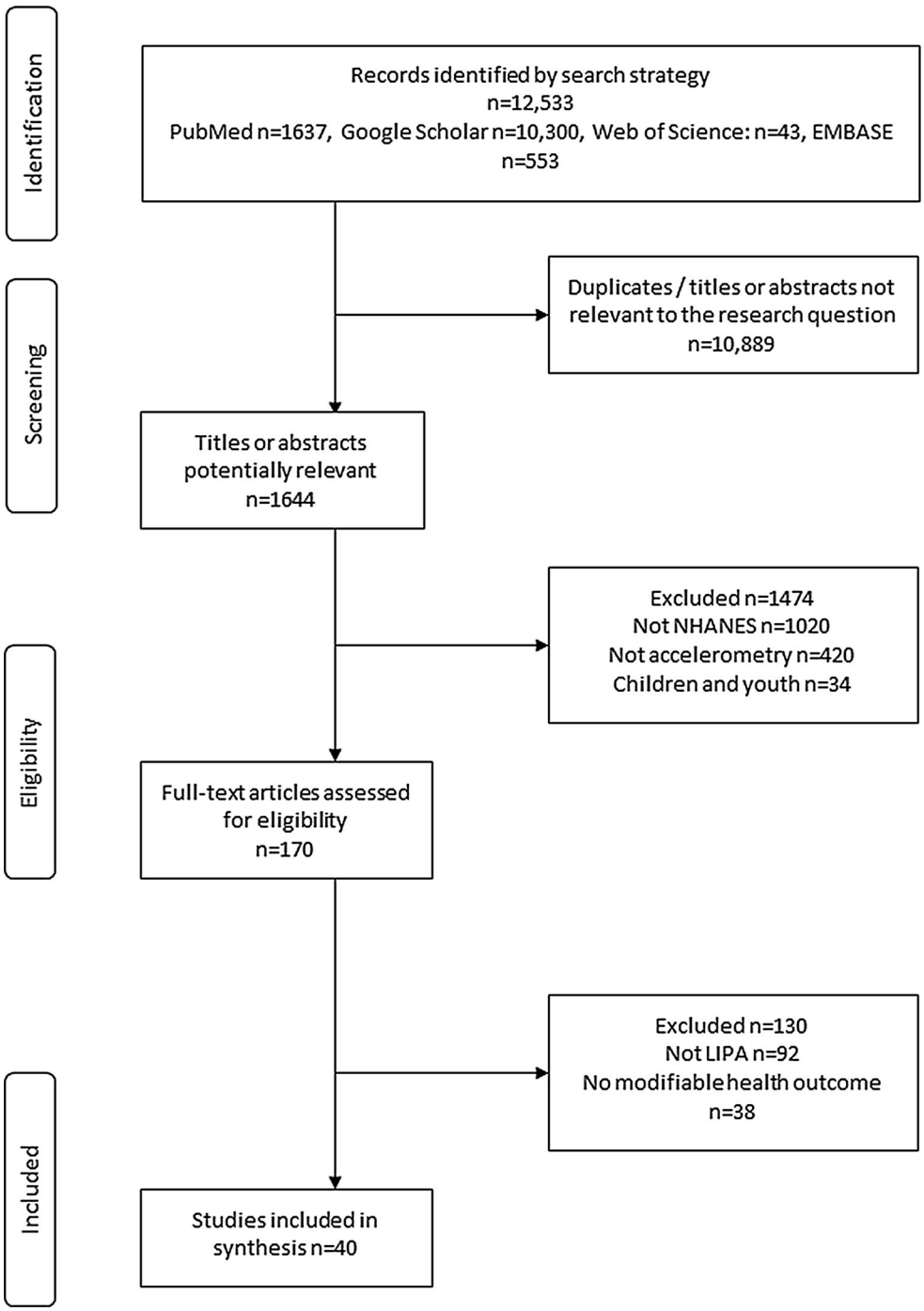

Fig. 1 Article screening process. *LIPA* light-intensity physical activity, *NHANES* National Health and Nutrition Examination Survey

500 cpm. The upper limit of LIPA was 1951 or 2019 cpm in all studies. Four reports differentiated between lower and higher LIPA, using different classifications [23, 30, 31, 56], and one study performed analyses using two different cut-off values for LIPA: 100–760 and 100–1951 [27]. One study did not provide cpm-specific information on cut-off points [52]. In all studies, a valid day was defined as one with ≥10 h of accelerometer wear time. Most studies included participants with at least 4 valid days, but four studies required only at least 1 valid day [20, 23, 55, 57] and two provided no information on the number of required valid days [47, 48]. Thirteen studies adjusted for MVPA, and five adjusted for both MVPA and SB. Seven studies were of high quality, 29 were of moderate quality, and 4 were of low quality.

Table 2 Characteristics of the included cross-sectional studies

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
General adult population										
Biomarkers WC, SBP, DBP, HDL-C, CRP, LDL-C, fasting TAG, fasting plasma glucose, fasting and insulin, HOMA-S, HOMA-β	For statistical analyses (1) (2) (3). All models adjusted for age, sex and race/ethnicity. Marital status, education, work status, poverty, smoking, depressive symptoms, energy intake, saturated fat intake, caffeine, alcohol use, general health rating, previous diagnosis of cancer or malignancy, CVD, or diabetes, and current diabetic, antihypertensive, lipidemic, or other CVD medication. Covariates included as through backward elimination ($p < 0.2$)	Full sample: $N = 2185$; fasting subsample: $N = 923$	Adults ≥20 years	Full sample: 51.9% females, fasting subsample: 47.6% females Full sample and fasting subsample not significantly different from all eligible participants	2005/2006	LIPA: 100–1951 cpm), MVPA: ≥1952 cpm ≥60 min ≥4 valid days out of 7 ≥10 h NR	1: LIPA significantly positively associated with TAG, fasting insulin, HOMA-β, HOMA-S, HDL, WC Detrimental association with SBP No association with CRP, LDL-C, plasma glucose 2: Reallocating sleep (30 min/day) to LIPA not beneficial; reallocating SB to LIPA: lower TAG, insulin, HOMA-β and higher HOMA-S Detrimental: higher SBP/DBP 3: Benefits of LIPA most pronounced in very short sleepers (≤5 h): HDL-C, HOMA-β, HOMA-S Benefits of LIPA least pronounced in 6-h sleepers	(1) Single and partition models (2) Isotemporal substitution models (3) Interaction analyses	11/12	[19]
Biomarkers WC, BMI, SBP, DBP, HDL-C, LDL-C, TAG, fasting plasma glucose and insulin, HOMA-%S, HOMA-%β	Age, sex, ethnicity, education, marital status, family poverty income ratio, smoking, alcohol, total energy intake, saturated fat intake, diabetes, history of CVD, cancer, family history of CVD, family history of diabetes, antihypertensive drugs, other cardiovascular drugs, diabetes drugs, lipid-lowering drugs, MVPA. Covariates retained in backward elimination: $p < 0.2$ for retention	Full sample: $N = 4614$, fasting subsample: $N = 2003$, OGTT subsample: $N = 851$	Adults ≥20 years Mean age 47 ± 17 years	52% of the sample were females Sample reweighted. Reweighted data of study sample similar to all eligible participants, except for smoking status	2003/2004 and 2005/2006	Low LIPA: 100–761 cpm, high LIPA: 762–1951 cpm MPA: 1952–5724 cpm VPA: ≥5725 cpm ≥60 min ≥4 valid days, including ≥1 weekend day ≥10 h NR	All intensities of physical activity significantly beneficially associated with WC, CRP, TAG, fasting insulin, HOMA-%β and HOMA-%S; low LIPA associated with higher SBP Low LIPA not associated with BMI, HDL-C, fasting glucose, and 2-h plasma glucose	Linear regression	9/12	[30]
Biomarkers BMI, WC, BP, HDL-C, CRP, fasting LDL-C, TAG, plasma glucose, insulin, HOMA	Age, sex, race/ethnicity, marital status, education, work status, poverty-to-income ratio, smoking status, consumption of caffeine and alcohol, diet, self-reported health (SF-12), previous diagnosis of cancer, diabetes, cardiovascular disease stroke and diabetes; current use of diabetic, antihypertensive or lipidemic drugs	$N = 1937$	Adults 21–64 years	51% of the sample were females Study sample significantly more males, older, significantly different BMI distribution, significantly less participants with self-reported poor health	2005/2006	LIPA: 100–1951 cpm, MVPA: >1952 cpm ≥60 min ≥5 valid days ≥10 h NR	1: LIPA beneficially association with WC, TAG, insulin, HOMA 2: Replacing sleep or ST with LIPA: favorable effects on LDL-C, TAG, glucose, insulin, and HOMA	(1) Linear regression (2) Compositional analysis paradigm	7/12	[22]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
TAG, HDL-C, BP, WC	Age, sex, race/ethnicity, MVPA	$N = 1371$	Adults ≥18 years	50% female, 71% non-Hispanic White Analytic sample was reweighted to be representative of the US population	2005/2006	LIPA: 760–2019 cpm, MVPA: ≥2020 cpm NR ≥1 valid day ≥10 h 5.3 ± 0.08 14.0 ± 0.08 h/day	Per 30 min LIPA: lower odds of elevated TAG (OR 0.89, 95% CI 0.83–0.97), low HDL-C (OR 0.87, 95% CI 0.83–0.92), elevated WC (OR 0.88, 95% CI 0.83–0.94), metabolic syndrome (OR 0.87, 95% CI 0.80–0.96) and diabetes (OR 0.67, 95% CI 0.55–0.82) independent of MVPA No association between LIPA and fasting glucose and BP	Logistic regression	7/12	[20]
Red blood cell distribution width	Age, sex; race/ethnicity; poverty-to-income ratio, dual-energy x-ray absorptiometry-determined body fat percentage; cotinine, physician diagnosis of diabetes, cancer, coronary artery disease; mean BP; glomerular filtration rate; HDL, MVPA and ST, iron, CRP	$N = 4538$	Adults ≥20 years Mean age 44.6 year		2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	Higher levels of LIPA associated with lower red blood cell distribution width	Multivariable linear and logistic regression	8/12	[34]
HbA_{1c}	Diabetes risk (low, moderate, high), sex, race/ethnicity, MVPA and wear time	$N = 5302$	Adults ≥18 years	51.1% female	2003/2004 and 2005/2006	LIPA: 100–2019 cpm, MVPA: >2020 cpm ≥60 min ≥4 valid days ≥10 h NR	Low-risk group (based on age and BMI) had higher LIPA counts compared with the moderate- and high-risk groups LIPA associated with HbA_{1c} in the low-risk group only	ANOVA	3/12	[24]
Metabolic syndrome Biomarkers WC, TAG, HDL-C, BP, glucose	Sex, age, race/ethnicity, smoking, alcohol, poverty-to-income ratio, embedded MVPA, bouted MVPA	$N = 1974$	Adults ≥20 years	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MPA: ≥2020–5998 cpm VPA ≥5999 cpm ≥90 min ≥4 valid days ≥10 h NR	1: Association of bouted LIPA with the metabolic syndrome, WC and TAG 2: Bouted, but not sporadic, LIPA independently associated with the metabolic syndrome For every 30 min/day bouted LIPA 4% reduction in relative odds of the metabolic syndrome (OR 0.96, 95% CI 0.93–0.98)	1. Logistic regression 2. Multivariable models	10/12	[53]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
Metabolic syndrome (AHA/NHLBI guidelines) Biomarkers Fasting TAG and glucose, total cholesterol, TAG, HDL-C, CRP, SBP, DBP, WC, triceps skinfold, subscapularis skinfold, BMI Mental and physical health	Age, sex, BMI, smoking status, race/ethnicity, poverty-to-income ratio, history of coronary heart disease and stroke	Full sample: $N = 5538$, with fasting glucose: $N = 2538$ With fasting TAG: $N = 2527$	Adults ≥18 years		2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	1: Beneficial association (differences between LIPA deciles) between LIPA and OR for having metabolic syndrome and self-reported mental and physical health 2: Linear inverse association for CRP, TAG, WC, triceps skinfold and BMI with LIPA LIPA is not associated with total cholesterol and fasting glucose	1. Wald test, design-based likelihood ratio Chi-square test 2. Multivariate logistic regression	9/12	[38]
NAFLD Secondary outcomes Biomarkers BMI, skinfolds, WC, fasting plasma insulin, HDL-C, BP, aminotransferases	Age, sex, race/ethnicity, smoking status, education, BMI, diabetes	$N = 3056$	Adults ≥20 year	41% with and 59% without NAFLD, 9.4% diabetes mellitus	2003/2004 and 2005/2006	LIPA: 100–2019 cpm, MPA: 2020–5999 cpm, VPA: >6000 cpm ≥60 min ≥4 valid days ≥10 h NR	No significant differences in LIPA counts/min/day between the NAFLD and non-NAFLD groups	Chi-square test for group differences	6/12	[25]
Obesity (BMI) and low back pain	Age, race and ethnicity, alcohol intake, education, income, self-reported diabetes, cardiac diseases, stroke, COPD and osteoarthritis.	$N = 6796$	Adults		2003/2004	LIPA: 100–1951 cpm MPA: 1952–5723 cpm VPA: ≥5724 cpm NR NR	LIPA: not associated with low back pain in overweight, obese and ultraobese participants	Adjusted weighted logistic regression	4/12	[54]
Self-reported chronic widespread pain "During the past month, have you had a problem with pain that lasted more than 24 hours?"	Age, sex, race/ethnicity, education, BMI, arthritis, diabetes mellitus, asthma, cancer (non-skin), pulmonary disease, myocardial infarction, congestive heart failure, stroke, mental health, valid monitor wear time	$N = 3952$	Adults ≥20 years	51.39% were females Study sample representative of total sample	2003/2004	Low LIPA: 100–759 cpm High LIPA: 760–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥1 valid day (sensitivity analysis showed no difference between participants with 1 or more days vs. 4 days of accelerometer wear time) ≥10 h NR	Low and high LIPA had no effect on chronic widespread pain	Multiple linear regression	5/12	[23]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
Bone mineral density of the hip and lumbar spine	Age, cotinine, BMI, ethnicity, intake of calcium, alcohol consumption, vitamin D levels, use of prednisone, family history of osteoporosis, levels of parathyroid hormones	$N = 2117$ for femur data $N = 1942$ for spine data	Adults ≥22 year	For femur data (959 females, data loss 56%); for spine data (889 females, data loss 59%)	2005/2006	LIPA: 100–1951 cpm; MVPA: 1952–5724 cpm VPA: >5724 cpm ≥60 min ≥5 valid days, including at least one weekend day, ≥10 h NR	In men, LIPA not significantly associated with BMD at the femur and subregions In women positively associated with total femur BMD and BMD of all subregions	Multiple linear regressions, with BMD as the dependent variable	8/12	[21]
Physical function in five domains (i.e. ADL, instrumental ADL, leisure activities, lower extremity activities, and general activities)	Sex, BMI, race/ethnicity, self-rated health, MVPA, accelerometer wear time	$N = 5700$	Adults 20–85 years Mean age 51.89 years	51.3% female	2003/2004 and 2005/2006	PA intensities not defined in terms of cpm ≥4 valid days ≥10 h NR	Disability inversely correlated with LIPA Individuals with a disability: fewer minutes of LIPA compared with adults with no disability Age moderates LIPA among those who report limitations in leisure/social activities and lower extremity mobility	Independent sample *t*-tests, ordinary least squares regression	6/12	[52]
Depression via PHQ-9	Age, race and ethnicity, sex, income, marital status, self-reported health	$N = 4058$	Adults ≥20 years		2005/2006	LIPA: 500–2019 cpm MPA: 2020–5998 cpm VPA: ≥5999 cpm 1 valid day ≥10 h	Participants with mild and moderate-to-severe depression spend less time in LIPA compared with participants with minimal depression	Chi-square test or *t*-test	6/12	[55]
Special adult population										
CRP in pregnancy	BMI, smoking status, history of adverse pregnancy outcomes	$N = 294$	Pregnant women >16 years	51.9% of eligible sample of all participants	2003/2004 and 2005/2006	Matthews's cut-points LIPA: 100–760 cpm MVPA: >761 cpm and Freedson's cut-points LIPA: 100–1951 cpm MVPA: >1951 cpm ≥60 min 4 valid days ≥10 h NR	LIPA according to Freedson's cut-points associated with lower levels of CRP in the second trimester of pregnancy ($\beta = -0.002$) No association in the first or third trimester	Multivariable linear regression	8/12	[27]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
Adults with chronic diseases										
Biomarkers Fasting TAG, LDL-C, and glucose, non-fasting CRP, HDL-C, total cholesterol, SBP, DBP, cotinine, WC, BMI Biomarkers Secondary outcomes Multiple cardiovascular disease risk factors, metabolic syndrome	Age, coronary heart disease/stroke history, smoking, education, marital status, poverty-to-income ratio, race/ethnicity, BMI, physical function, and arthritis	$N = 746$	Adults ≥18 years with diabetes	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MPA: 2020–5998 cpm VPA: ≥5999 ≥60 min ≥4 valid days ≥10 h NR	Men (18–64 years). For every 10 min bout LIPA 1% less likely unfavorable cholesterol profile, 2% less likely high WC (1 min and 10 min bout) No association with high BP, high CRP, high TAG, obesity, smoking and multiple cardiovascular risks Women (18–64 years). For every 10 min bout LIPA 7% less likely high WC, for every 1 min bout 2% (10 min bout 1%) less likely obesity, for every 10 min bout 1% less likely smoking, for every 1 and 10 min bout LIPA 1% less likely multiple cardiovascular risk factors No association with high BP, high CRP, unfavorable cholesterol profile, high TAG, men (65+ years). For every 1 and 10 min bout LIPA 1% less likely obesity No association with high BP, high CRP, unfavorable cholesterol profile, high TAG, high WC, smoking and multiple cardiovascular disease risk Women (65+ years). For every 1 and 10 min bout LIPA 1% (2%) less likely high CRP, 1% less likely unfavorable cholesterol profile, 1% less likely obesity, 2% less likely smoking and 1% less likely multiple CVD risk factors No association with high BP, high TAG, and high WC	Logistic regression	7/12	[42]
Vision in diabetes	Age, sex, race/ethnicity, marital status, education, poverty-to-income ratio, cotinine, comorbidities, BMI, SBP, DBP, CRP, HDL-C, homocysteine, HbA_{1c}, MVPA	$N = 670$	Adults with diabetes 20–85 years	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	1: Participants with visual impairment spend significantly less time in LIPA than participants with uncorrected refraction error or normal sight 2: 1 h increment of LIPA: 38% less likelihood of visual impairment	(1) Wald Test, design-based likelihood ratio test (2) Multinominal logistic regression	9/12	[43]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
Biomarkers Inflammatory markers WBC count, neutrophil count, CRP	Age, sex, race/ethnicity, education, comorbidity index, BMI, CRP, WBC, cotinine, homocysteine, HbA_{1c}, accelerometer wear time, number of valid accelerometer days	$N = 754$	Adults with diabetes		2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h 14.04 h/day 6.06 days	1: Dose–response relationship (group differences between LIPA quartiles) between LIPA and WBC and neutrophil count, LIPA not associated with CRP 2: LIPA inversely associated with WBC counts, neutrophil count, but not CRP	(1) Linear regression (2) Multivariable linear regression	7/12	[44]
CRP	Age, sex, race/ethnicity, lipid-lowering medication use and cardiovascular disease history, cotinine, lipid levels	$N = 3771$	Age not indicated Adults with and without diabetes	51% female, 12% diabetes mellitus	2003/2004 and 2005/2006	LIPA: 100–1951 cpm MPA: 1952–5724 cpm Hard PA: 5725–9498 cpm Very hard PA: ≥9499 cpm ≥60 min ≥4 valid days ≥10 h wear time NR	1: LIPA inversely associated with CRP in non-diabetic women ($\beta = -0.0574$), but not in men 2: Diabetic men and women significantly less LIPA than non-diabetic men and women	(1) Logistic regression, and multivariate linear regression (2) Wald, Chi-square tests	5/12	[26]
Weight status	Age, sex, race/ethnicity, poverty-to-income ratio, coronary heart disease, stroke, arthritis, accelerometer wear time	$N = 126$	34–84 year Cancer survivors Mean age 68.3 years	Study sample reweighted, 76.8% females	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MPA: 2020–5998 cpm VPA: ≥5999 cpm ≥60 min ≥4 valid days ≥10 h NR	Cancer survivors participate in 294.8 ± 8.2 min/day LIPA No association between LIPA and weight status	Multivariate linear regression for LIPA	7/12	[39]
Biomarkers BMI, WC, BP, CRP, HDL-C, LDL-C and total cholesterol, fasting TAG, fasting glucose, fasting insulin, homocysteine, HbA_{1C}, WBC, neutrophils, insulin resistance (HOMA)	Age, sex, race/ethnicity, BMI, cotinine, poverty-to-income ratio, and comorbidity index, drug therapy	$N = 227$	28–85 years Cancer survivors Mean age 68.1 years	69% females, no difference between study sample and eligible sample	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	LIPA inversely associated with WBC, neutrophils, insulin, and insulin resistance No association with BMI, CRP, SBP, DBP, fasting glucose, HbA_{1C}, HDL-C, LDL-C and total cholesterol, TAG, homocysteine	Multivariate linear regression	7/12	[37]
WC	Age, ethnicity, education, marital status, total energy intake, MVPA	$N = 103$	Prostate cancer survivors Mean age 75.4 years	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–1951 cpm MVPA: ≥1952 cpm ≥60 min NR ≥10 h 14.4 h/day	No significant association between LIPA and WC	Linear regression	9/12	[47]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
Adiposity Secondary outcome Serum insulin	Age, ethnicity, education, marital status, total energy intake, MVPA	$N = 111$ $N = 100$ for WC analysis, $N = 106$ for BMI analysis	Breast cancer survivors Mean age 69.2 years		2003/2004 and 2005/2006	LIPA: 100–1951 cpm MVPA: ≥1952 cpm ≥60 min NR ≥10 h 14.0 h/day	LIPA inversely associated with serum insulin levels, but not WC and BMI	Linear regression	9/12	[48]
WBC and neutrophil levels	Age, sex, race/ethnicity, poverty-to-income ratio, comorbidity index, BMI, homocysteine, CRP, accelerometer wear time, functional disability, antidiabetic, BP-lowering or cholesterol-lowering medication	$N = 238$	Current and former smokers with self-reported COPD		2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	LIPA inversely associated with WBC and neutrophil count in current and former smokers 60 min increase in LIPA associated with a 2% decrease in WBC and a 6% decrease in neutrophils	Multivariable linear regression	7/12	[46]
Metabolic syndrome Biomarkers SBP, DBP, mean arterial pressure, fasting glucose, HDL-C, TAG, WC	Age, sex, race, level of education, household income, working status, marital status, number of people in household, pack-years of smoking, shortness of breath, and comorbid conditions, BMI	$N = 223$	COPD patients	48.9% female	2003/2004 and 2005/2006	LIPA: 100–1951 cpm MVPA: ≥1952 cpm ≥60 min ≥4 valid days ≥10 h NR	LIPA negatively associated with WC and fasting glucose level No association between LIPA and the metabolic syndrome, HDL-C, TAG, and MAP	Univariate and multivariate logistic regression	8/12	[50]
COPD and anthropometrical and clinical characteristics	Age, sex, race, level of education, household income, working status, marital status, number of people in household, comorbid conditions, respiratory symptoms, self-reported health, pack-years of smoking, BMI	$N = 224$ COPD, $N = 1386$ comparison group	COPD patients (current smokers or with smoking history) and controls (current smokers or with smoking history)	COPD: 49.1% female Control: 35.7% female	2003/2004 and 2005/2006	LIPA: 100–1951 cpm MVPA: ≥1952 cpm ≥60 min ≥4 valid days ≥10 h 6.4 ± 0.9 days 931.67 ± 157.40 min/day	1 and 2: COPD patients spend significantly less time with LIPA compared with controls 3: LIPA and BMI, age, self-reported health significantly negatively associated	(1) Chi-square test (2) Lincom procedure (3) Linear regression (multiple regression)	6/12	[51]
Kidney function (eGFR estimated from serum creatinine)	Age, age squared, race, current smoking, BMI, CRP, total cholesterol, HDL, MAP	$N = 2117$	Adults with mild to moderate kidney disease ≥18 years	47% females Study sample significantly different from eligible sample in smoking status	2003/2004 and 2005/2006	LIPA: 100–1952 MVPA ≥1952 ≥60 min 4 valid days ≥10 h NR	1: Participants with normal kidney function participate in more LIPA 2: LIPA is positively associated with kidney function in women regardless of diabetes status, in men only in those without diabetes an additional hour LIPA/day: 3–6% higher eGFR	(1) Chi-square test, Wald test, (2) Linear regression	7/12	[29]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
Metabolic syndrome (National Cholesterol Education Program Adult Treatment Panel III definition) Biomarkers WC, HDL-C, TAG, BP, glucose	Age, sex, BMI, self-reported general health	$N = 566$	Adults with osteoarthritis	51.0% have metabolic syndrome	2003/2004 and 2005/2006	Low LIPA: 100–759 cpm High LIPA: 760–2019 cpm MVPA: ≥2020 cpm ≥60 min 4–7 valid days, including at least 1 weekend day ≥10 h 13.9 h/day with metabolic syndrome 14.4 h/day without metabolic syndrome	1: OR for metabolic syndrome inversely associated with LIPA/ significant differences in LIPA between participants with and without metabolic syndrome 2: Participants with low HDL-C, high TAG and high glucose spend less time in low LIPA, participants with large WC, high BP, and high fasting glucose spend less time in high LIPA	(1) and (2) ANOVA	8/12	[31]
Biomarkers BMI, WC, CRP, WBCs, neutrophil level, fasting TAG, fasting glucose, HbA_{1C}, homocysteine level	Mobility limitation, age, sex, race/ethnicity, poverty-to-income ratio, BMI, cotinine, comorbidity index, accelerometer wear time, MVPA	$N = 5575$	Adults with mobility limitations ≥20 years	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h 14.4 h/day without disability 13.9 h/day with disability	1: Participants with mobility limitations engage in less LIPA compared with those without 2: LIPA inversely associated with BMI and WC, but not CRP, WBC, neutrophils, HDL-C, TAG, glucose, HbA_{1C}, homocysteine 3: An increase of 60 min/day LIPA: RR for chronic disease would be expected to decrease by a factor of 0.95	(1) Wald test or design-based likelihood ratio test (2) Multivariable linear regression (3) Multivariable Poisson regression	8/12	[45]
General older population										
Depression (PHQ-9)	Age, sex, race/ethnicity, marital status, education, comorbidity index, BMI, functional disability	$N = 708$	Older adults >65 years	14.9% report depression	2005/2006	LIPA: 100–2019 cpm MPA: 2020–5998 cpm VPA: ≥5999 cpm ≥60 min ≥4 valid days ≥10 h NR	For every 1 h of increase in LIPA OR 0.80, 95% CI 0.67–0.95, to have depression symptoms	Multivariate logistic regression	7/12	[32]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
Diabetes comorbidities (arthritis, hypertension, hearing problem, vision problem, stroke problem, weight problem)	Age, sex, race/ethnicity, marital status, education, comorbidity index, self-reported health, BMI	$N = 1743$	Older adults >65 years	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MPA: 2020–5998 cpm VPA: ≥5999 cpm ≥60 min ≥4 valid days ≥10 h NR	1: Participants with diabetes have significantly lower amount of LIPA than those without diabetes 2a: Participants with diabetes and arthritis, hypertension or weight problems have significantly lower LIPA than participants without comorbidities 2b: Participants without diabetes but with hypertension or stroke problems have significantly lower LIPA than participants without morbidities	(1) Adjusted Wald test, (2) design-based likelihood ratio test	6/12	[33]
Biomarkers BMI, WC, triceps skinfold, subscapular skinfold, SBP, DBP, CRP, HDL-C, fasting LDL-C, total cholesterol, fasting TAG, fasting glucose, fasting insulin, homocysteine, HbA_{1c}	Age, sex, race/ethnicity, poverty-to-income ratio, cotinine, BMI, comorbidity index, physical functional disability, accelerometer wear time, number of valid days	$N = 1496$	Older adults ≥65 years		2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	1: LIPA ≥300 vs. <300 min/week associated with more favorable values for BMI, SBP, WC, triceps skinfold, CRP, WBCs, neutrophils, glucose, insulin, insulin resistance, and HbA_{1C} LIPA not associated with total and LDL cholesterol and TAG 2: LIPA associated with comorbidity index, <300 min/week group had 1.18 greater incident rate ratio for having chronic disease	(1) Wald test (2) Poisson regression	7/12	[40]
Balance (modified Romberg Test of Standing Balance) Difficulty with falling (via questionnaire)	Age, sex, race/ethnicity, education, BMI, comorbidity index, vision, hearing, medication use	$N = 1831$	Adults 40–85 years	Study sample not different from eligible sample except for education and vision	2003/2004	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	LIPA associated with better functional balance For every hour increase in LIPA participants 10% more likely to have functional balance Participants with dysfunctional balance and difficulty with falling engage in less LIPA	Multivariable logistic regression	9/12	[35]
ABI FRS	Age, sex, race/ethnicity, lipid-lowering medication, BMI, diabetes status, CRP, cotinine, lipids, FRS	$N = 561$	Adults >40 years	Study sample significantly different from eligible sample in age, LDL-C, total cholesterol, smoking status, diabetes status and sex, significantly different in race, BMI, CRP, pulse pressure, TAG	2003/2004	LIPA: 100–1952 cpm, MVPA ≥1952 cpm ≥60 min 4 valid days ≥10 h NR	1: Time spent in LIPA does not differ between ABI groups 2: Time spent in LIPA not related to FRS in either group	(1) Chi-square test Multiple logistic regression (2) Multiple linear regression, partition models	10/12	[28]

Table 2 continued

Outcomes	Covariates[a]	Participants			NHANES wave	Exposure [cut-point; non-wear criteria; minimum wear; average wear (days and min/day)]	Major findings	Statistics	Study quality	Reference
		Sample size	Age	Characteristics						
PSA	Age, height, weight, BMI, race/ethnicity; marital status, poverty-to-income ratio, diet, medication, alcohol intake, cotinine, total cholesterol, HDL-C, BP, CRP, diabetes, WBC count, basophils, eosinophils, MVPA	$N = 1672$	Men ≥40 years Mean age 55.6 years	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h NR	1: Participants with elevated PSA engage in significantly less LIPA (1 min bouts) 2: LIPA (10 min bouts) was significantly associated with PSA 3: LIPA (10 min and 1 min bouts) was significantly associated with PSA For every 1 h increase in LIPA, 18% (OR 0.82, 95% CI 0.68–1.00) less likely to have elevated SPA concentration	(1) Adjusted Wald test (2) Linear regression (3) Logistic regression	10/12	[36]
Tinnitus	Age, sex, race/ethnicity, marital status, hypertensive medication, BMI, BP status, poverty-to-income ratio, cotinine	$N = 473$	Older adults (70–85 years)		2005/2006	LIPA: 100–2019 cpm MPA: 2020–5998 cpm VPA: ≥5999 ≥60 min ≥4 valid days ≥10 h NR	1: Participants with tinnitus participate in less LIPA compared with participants without tinnitus Participants with tinnitus and hypertension participate in less LIPA compared with participants with hypertension but no tinnitus 2: For every 1 min increase in LIPA, participants with and without hypertension 1% less likely to have tinnitus/for every 60 min LIPA 16% resp. 21% (with and without hypertension) less likely to have tinnitus 3: LIPA marginally associated with tinnitus ($p = 0.05$)	(1) Wald Test (2) Design-based likelihood ratio test (3) logistic regression	7/12	[41]
Adiposity (WC and BMI), CRP, insulin resistance (HOMA-IR)	Age, race/ethnicity, education, marital status, family income, total energy and alcohol intake, reproductive health data, WC, MVPA	$N = 1031$	Postmenopausal women Mean age 63.6 years	Study sample reweighted	2003/2004 and 2005/2006	LIPA: 100–1951 cpm MVPA: ≥1952 cpm ≥60 min ≥4 valid days, including ≥1 weekend day ≥10 h 14.5 h/day	LIPA beneficially associated with BMI, WC, CRP, insulin, and HOMA-IR, but not with fasting glucose	Linear regression	10/12	[49]

WC waist circumference, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *HDL-C* high-density lipoprotein cholesterol, *CRP* C-reactive protein, *LDL-C* low-density lipoprotein cholesterol, *TAG* triglycerides, *HOMA-S (HOMA%S)* homeostasis model assessment of insulin sensitivity, *MPA* moderate physical activity, *VPA* vigorous physical activity, *HOMA- β (HOMA%β)* homeostasis model assessment of β-cell function, *HOMA-IR* homeostasis model assessment of insulin resistance, *CVD* cardiovascular disease, *LIPA* light-intensity physical activity, *MVPA* moderate to vigorous physical activity, *NR* not reported, *BMI* body mass index, *OGTT* oral glucose tolerance test, *HOMA* homeostasis model assessment, *ST* sedentary time, *BP* blood pressure, *HbA1c* glycosylated hemoglobin, *NAFLD* non-alcoholic fatty liver disease, *WBC* white blood cell, *COPD* chronic obstructive pulmonary disease, *eGFR* estimated glomerular filtration rate, *MAP* mean arterial pressure, *RR* risk ratio, *ABI* ankle–brachial index, *PSA* serum prostate-specific antigen, *NHANES* National Health and Nutrition Examination Survey, *cpm* counts per minute, *PA* physical activity, *OR* odds ratio, *CI* confidence interval, *ANOVA* analysis of variance, *SB* sedentary behavior, *FRS* Framingham Risk Score, *ADL* activities of daily living, *AHA* American Heart Association, *NHLBI* National Heart, Lung, and Blood Institute, *SF-12* Short-Form 12, *PHQ* Patient Health Questionnaire

[a] Only those covariates that studies adjusted for in the analysis of light-intensity activity are listed

Table 3 Characteristics of the included longitudinal studies

Outcomes	Covariates	Participants			NHANES wave	Follow-up	Exposure	Major findings	Statistics	Study quality	Reference
		Study sample	Age	Mortality							
Mortality assessed as HR (hazard of death in 3-year follow-up)	Age, sex, race, education, smoking, alcohol use, lung disease, mobility limitations, comorbid conditions (history of congestive heart failure, coronary heart disease, stroke, diabetes, hypertension, cancer), WC, CRP, urine albumin-to-creatinine ratio MVPA, ST	$N = 3626$ $N = 3243$ without chronic kidney disease $N = 383$ with chronic kidney disease	Adults ≥20 years	137 deaths	2003/2004	Mean 2.86 ± 0.64 years 10,390 person-years	Low LIPA: 100–499 cpm High LIPA: 500–2019 cpm MVPA: ≥2020 cpm NR ≥4 valid days ≥10 h 14.06 ± 1.4 h/day	2 min/h tradeoff of ST with an equal duration of high LIPA associated with a lower mortality risk in the entire cohort and the chronic kidney disease subgroup Low LIPA not associated with reduced mortality	Multivariable Cox regression	10/12	[56]
Mortality	Age, sex, race/ethnicity, education, smoking status, mobility limitations, BMI, and the presence of comorbid conditions, wear time	$N = 3029$	Adults 50–79 years	387 deaths	2003/2004 and 2005/2006	Mean 6.5 years 19,757 person-years	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥1 valid day ≥10 h	Greater LIPA is associated with lower mortality independent of MVPA Replacing 30 min of ST with LIPA associated with reduced mortality risk (HR 0.80, 95% CI 0.75–0.85)	Isotemporal substitution Cox proportional hazards	9/12	[57]

Table 3 continued

Outcomes	Covariates	Participants			NHANES wave	Follow-up	Exposure	Major findings	Statistics	Study quality	Reference
		Study sample	Age	Mortality							
All-cause mortality	MVPA, age, sex, race/ethnicity, cotinine, weight status, poverty level, CRP and comorbid illness	$N = 5575$ participants	Adults aged 20–85 years	511 deaths	2003/2004 and 2005/2006	Mean 6.5 years	LIPA: 100–2019 cpm MVPA: ≥2020 cpm ≥60 min ≥4 valid days ≥10 h	For every 60 min increase, LIPA participants had a 16% reduced hazard of all-cause mortality (HR 0.84, 95% CI 0.78–0.91; $p < 0.001$)	Cox proportional hazard	10/12	[58]

NHANES National Health and Nutrition Examination Survey, *WC* waist circumference, *CRP* C-reactive protein, *BMI* body mass index, *MVPA* moderate to vigorous physical activity, *cpm* counts per minute, *NR* not reported, *LIPA* light-intensity physical activity, *ST* sedentary time, *HR* hazard ratio, *CI* confidence interval

3.2 General Adult Population

3.2.1 Cardiometabolic Outcomes

A total of nine studies reported on markers of cardiometabolic health, including markers of fat and glucose metabolism, measures of adiposity, blood pressure (BP), C-reactive protein (CRP), red blood cell distribution width, the metabolic syndrome, diabetes and non-alcoholic fatty liver disease (NAFLD) in the general adult population.

3.2.2 Markers of Lipid Metabolism

Two high-quality [19, 53] and four moderate-quality studies [20, 22, 30, 38] reported beneficial associations between LIPA and triglycerides (TAG). One high-quality [19] and one moderate-quality study [20] found a significant beneficial association between LIPA and high-density lipoprotein (HDL)-cholesterol. Howard and colleagues reported a beneficial association between high LIPA and HDL-cholesterol but not between low LIPA and HDL-cholesterol [30]. One moderate-quality study reported no association with total cholesterol [38].

3.2.3 Markers of Glucose Metabolism

One high-quality [19] and two moderate-quality reports found significant favorable associations between fasting insulin and LIPA [22, 30]. Similarly, positive associations were documented for homeostasis model assessment of β-cell function (HOMA-β), homeostasis model assessment of insulin sensitivity (HOMA-S) [19], HOMA-%β and HOMA-%S [30], and HOMA [22]. A low-quality study found a risk status-dependent association between glycosylated hemoglobin (HbA_{1c}) and LIPA; only participants with a low (not moderate or high) diabetes risk benefited from LIPA [24].

A lack of association with fasting glucose was reported in one high-quality [19] and two moderate-quality investigations [20, 38]. Howard et al. found a beneficial association between high LIPA, but not low LIPA, and fasting or 2-h plasma glucose [30].

3.2.4 Measures of Adiposity

Measures of adiposity used in different studies included body mass index (BMI), waist circumference (WC) and triceps skinfold. Two high-quality [19, 53] and four moderate-quality studies [20, 22, 30, 38] found a significant beneficial association between LIPA and WC. One study differentiating between high and low LIPA found a significant beneficial association only in cases of high LIPA and BMI [30]. A further study of moderate quality reported

a significant beneficial association between LIPA and BMI and triceps skinfold [38].

3.2.5 Diabetes and Metabolic Syndrome

Diabetes was negatively associated with LIPA in one study of moderate quality [20], and two moderate-quality studies found a beneficial association between LIPA and the metabolic syndrome [20, 38]. One high-quality report provided evidence for a negative association for bouted (≥10 consecutive min), but not sporadic, LIPA with the metabolic syndrome [53].

3.2.6 Red Blood Cell Distribution Width

An investigation of moderate quality found that higher levels of LIPA were associated with lower red blood cell distribution width [34].

3.2.7 C-Reactive Protein

Two studies, both of moderate quality, reported an association between LIPA and CRP in the 2003/2004 and 2005/2006 cycles [30, 38]. Contrasting results were observed by Buman and colleagues in their analysis of the 2005/2006 wave [19].

3.2.8 Non-Alcoholic Fatty Liver Disease

No relationship between NAFLD and LIPA could be documented in a moderate-quality study [25].

3.2.9 Bone Mineral Density

The relationship between bone mineral density (BMD) and LIPA appears to be sex dependent; a significant association was reported in women's, but not men's, total femur BMD and BMD of all subregions [21].

3.2.10 Musculoskeletal and Functional Outcomes

Neither low back pain [54] nor chronic widespread pain [23] were associated with LIPA in these low-quality studies. Disability was inversely correlated with LIPA in one moderate-quality report [52].

3.2.11 Depression

A moderate-quality study found that participants with mild and moderate-to-severe depression spent less time in LIPA compared with participants with minimal depression [55].

3.3 Special Adult Populations

A study of moderate quality found that LIPA was associated with lower levels of CRP in the second, but not the first or third, trimester of pregnancy [27].

3.4 Adults with Chronic Diseases

Studies of patients with the following chronic diseases and conditions were available: diabetes, cancer, chronic obstructive pulmonary disease (COPD), kidney disease, osteoarthritis and mobility limitations. Samples in these studies were considerably smaller than in those in the general adult population.

3.4.1 Diabetes

Four reports on health outcomes in patients with diabetes were identified. One moderate-quality article analyzed the association between LIPA and biological markers, including BP, high CRP, unfavorable cholesterol profile, high TAG, high WC, obesity and multiple cardiovascular disease risk factors [42]. The results suggested, at least in the case of some outcomes, an age- and sex-specific association. In younger men (18–64 years of age), LIPA was favorably associated with cholesterol profiles and WC, as well as in older men (65+ years of age) with obesity. However, no association was observed in either of these age groups in patients with high BP, high CRP, high TAG and multiple cardiovascular disease risk factors. Furthermore, no relationship was documented in younger men with obesity, as well as older men with unfavorable cholesterol profile and high WC. Obesity and multiple cardiovascular risk factors were beneficially associated with LIPA in both younger and older women. A favorable association was shown in younger women with WC, as well as older women with CRP and unfavorable cholesterol profile. No association was found in younger women with high BP, high CRP, unfavorable cholesterol profile and high TAG, as well as older women with high BP, high TAG, and high WC [42].

A further moderate-quality report documented a positive relationship between LIPA and visual impairment in patients with diabetes [43]. LIPA was inversely associated with white blood cell (WBC) and neutrophil counts, but not CRP, in a moderate-quality study [44], which was consistent with the findings of a low-quality study [26].

3.4.2 Cancer

Four investigations examined the relationship between LIPA and health outcomes in cancer survivors. Two moderate-quality studies including patients with different

types of cancer in the 34–84 and 28–85 years age groups, respectively, found that there was no association between LIPA and weight status [39], and that LIPA was beneficially associated with WBC, neutrophils, insulin, and insulin resistance, but not BMI, CRP, systolic BP, diastolic BP, fasting glucose, HbA_{1c}, HDL-cholesterol, low-density lipoprotein (LDL) and total cholesterol, TAG, and homocysteine [37]. In two moderate-quality studies, Lynch and colleagues reported no relationship between LIPA and WC in prostate cancer survivors [47], and an inverse association between LIPA and serum insulin levels, but not WC and BMI, in breast cancer survivors [48].

3.4.3 Chronic Obstructive Pulmonary Disease

In a moderate-quality study, LIPA was inversely associated with WBC and neutrophil count in current and former smokers with COPD [46], and with WC and fasting glucose level in another study [50]. This report of moderate quality documented no association between LIPA and the metabolic syndrome, HDL-cholesterol, TAG, and mean arterial pressure [50]. BMI, age and self-reported health were significantly negatively associated with LIPA in a third study of moderate quality [51].

3.4.4 Kidney Disease

One moderate-quality study found that LIPA was positively associated with kidney function in women with mild to moderate kidney disease regardless of diabetes status, and only in men without diabetes [29].

3.4.5 Osteoarthritis

In a moderate-quality study, low, but not high, LIPA was inversely associated with the metabolic syndrome in patients with osteoarthritis [31].

3.4.6 Mobility Limitations

In a moderate-quality study, Loprinzi and colleagues reported an inverse association between LIPA and BMI and WC, but not CRP, WBC, neutrophils, HDL-cholesterol, TAG, glucose, HbA_{1c}, and homocysteine in participants with mobility limitations [45].

3.5 Older Adults

3.5.1 Neuropsychological Outcomes

One study of moderate quality documented a protective effect of LIPA against depression in older adults (≥65 years of age) [32], while another moderate-quality report found, in adults aged 70–85 years, that for every 1 min increase in LIPA, participants with and without hypertension were 1% less likely to have tinnitus, and, for every 60 min of LIPA, patients with and without hypertension were 16 and 21%, respectively, less likely to have tinnitus [41].

3.5.2 Biological Markers

The findings of a moderate-quality study in older adults were consistent with those for the general population [40]. Higher volumes of LIPA were associated with more favorable values for BMI, systolic BP, WC, triceps skinfold, CRP, WBC, neutrophils, glucose, insulin, insulin resistance, and HbA_{1c}, but not total and LDL cholesterol and TAG in adults aged ≥65 years. Furthermore, LIPA was beneficially associated with the adapted Charlson comorbidity index [40]. A high-quality study found that time spent in LIPA did not differ between ankle–brachial index (ABI) groups, and the time spent in LIPA was not related to Framingham Risk Score (FRS) in adults ≥40 years of age [28].

3.5.3 Markers of Cancer Risk

In a high-quality study, Loprinzi and Kohli reported a beneficial association between LIPA and serum prostate-specific antigen (PSA) values in men ≥40 years of age [36], while another high-quality study found LIPA to be beneficially associated with BMI, WC, CRP, insulin, and HOMA-IR, but not fasting glucose, in postmenopausal women [49].

3.5.4 Balance

In a moderate-quality report, LIPA was associated with better functional balance in adults aged 40–85 years [35].

3.6 Longitudinal Studies

Two high-quality studies [56, 58] and one moderate-quality study [57] examined the association between LIPA and overall mortality. Beddhu et al. analyzed the 2003/2004 wave, including adults ≥20 years of age [56], whereas another report only included adults aged 50–79 years from the 2003/2004 and 2005/2006 waves [57]. Loprinzi examined the data of adults aged 20–85 years from the 2003/2004 and 2005/2006 waves [58]. All three studies found a statistically significant beneficial association between LIPA and mortality.

3.7 Studies Subdividing the Light-Intensity Range

Four studies differentiated between lower and higher LIPA, using different classifications. Howard et al. defined low

LIPA as 100–761 cpm and high LIPA as 762–1951 cpm [30], while two other studies defined low LIPA as 100–759 cpm and high LIPA as 760–2019 cpm [23, 31]. Beddhu and colleagues applied the following classification: low LIPA 100–499 cpm, high LIPA 500–2019 cpm [56]. Howard and colleagues found that high LIPA was associated with a higher number of cardiometabolic markers, and the effect sizes were larger than in the case of low LIPA [30]. In the longitudinal study, mortality benefits for low LIPA were marginal, but meaningful in high LIPA [56]. The association between low LIPA, but not high LIPA, and the metabolic syndrome was significant [31]. Neither low nor high LIPA was associated with chronic widespread pain [23].

4 Discussion

Expanding the knowledge on health benefits of PA in the low-intensity ranges may have important public health implications, as engaging in and maintaining LIPA might be more appealing and feasible for currently inactive populations [59]. The aim of our review was to summarize available evidence on the relationship between LIPA and health outcomes based on the 2003/2004 and 2005/2006 NHANES datasets. We found that LIPA was beneficially related to several, but not all, important markers of cardiometabolic health and mortality. Major findings are summarized in Table 4.

4.1 Findings in Relation to Previous Studies

The consistent beneficial associations between LIPA and measures of insulin sensitivity in the general adult and older adult NHANES populations (but not in cancer survivors) are consistent with a current accelerometer study from Japan involving 807 participants [60], a smaller investigation in women [61] and randomized controlled intervention studies [62–64]. The majority of the studies included in our review documented no relationship between LIPA and fasting glucose, which is supported by a recent meta-analysis of randomized controlled trials [65]. Similar to other accelerometer studies [61], LIPA was shown to be beneficially related to some markers of lipid metabolism, namely TAG and HDL-cholesterol in the NHANES dataset. This finding is also upheld by randomized controlled studies [66, 67].

In the general adult and older adult NHANES populations, LIPA was consistently positively associated with different measures of adiposity. This finding is corroborated by other recent studies using different motion sensors and cut-off points [68, 69]. LIPA (251–1951 cpm) assessed using the ActiGraph GT1M was independently associated with a lower total body and trunk fat mass assessed using dual-energy X-ray absorptiometry regardless of the amount of time spent at other activity levels in 636 community-dwelling older adults (50–80 years of age) [68]. In the Lifestyle Interventions and Independence for Elders (LIFE) study (which used the Actigraph GT3X), both lower and higher LIPA (100–1040 and 1041–1951 cpm, respectively) were beneficially associated with BMI in 1130 community-dwelling older adults (70–89 years of age) [69]. In the 1134 participants of the ADDITION-PRO Actiheart study, LIPA was favorably associated with visceral and subcutaneous adipose tissue [70], while ActivPAL data in 195 female adolescents demonstrated lower BMI and sum of skinfold values [71]. Randomized controlled trials substantiate favorable changes in different measures of obesity following an LIPA intervention [72, 73].

Our findings also suggest a beneficial association between metabolic diseases and LIPA. The intensity of PA interventions in landmark diabetes prevention studies was typically defined as moderate [74, 75], but intensity was not device-based monitored. Recently, the randomized controlled PreDiabEx study demonstrated that a PA intervention with light intensity had clinically meaningful benefits for overweight and obese individuals with a high risk for diabetes [76]. LIPA was inversely associated with the metabolic syndrome in the general population and in patients with osteoarthritis in the NHANES dataset. This is consistent with a recent Japanese study of a triaxial accelerometer in 483 middle-aged participants [77], but in contrast to another study that evaluated the SenseWear Pro 3 armband in 370 Flemish adults [78]. Because of the use of three different devices and different definitions of the metabolic syndrome, direct comparison of these results is compromised.

Data on musculoskeletal outcomes were more sparse than for cardiometabolic outcomes. Recommendations for optimal bone health typically emphasize weight-bearing and high-impact activities [79]. In contrast, we report positive associations between LIPA and BMD in women. The Healthy Ageing Initiative, a recent triaxial accelerometer study, found LIPA to be negatively associated with cortical volumetric BMD of both the radius and tibia in a study population aged 70 years, which was considerably older than the NHANES sample (52 years of age) [80]. This age difference in the study populations might explain the contradictory findings. Consistent with a randomized controlled study using different balance assessment tests [81], we found a positive relationship between LIPA and balance in the NHANES data.

Patients with depression might find it especially challenging to engage in taxing PA. Our results, which are supported by a recent Cochrane review [82], suggest that PA must not necessarily be of high intensity to yield

Table 4 Major findings with LIPA in healthy adults and older adults

Outcome	Significant benefit from LIPA (no. of studies; high/moderate/low study quality)	No significant benefit from LIPA (no. of studies; high/moderate/low study quality)
TAG	6; 2/4/0 [19, 20[a], 22, 30[a], 38[a], 53[a]]	1; 0/1/0 In older adults ≥65 years [40]
HDL-C	3; 1/2/0 [19, 20[a]], for high LIPA [30[a]]	1; 0/1/0 For low LIPA [30[a]]
Total cholesterol	–	2; 0/2/0 [38[a], 40]
Fasting insulin	5; 2/3/0 [19, 22, 30[a], 40, 49[a]]	–
HOMA-β, HOMA-S, HOMA-%β, HOMA-%S HOMA-IR	4; 2/2/0 [19, 22, 30[a], 49[a]]	–
HbA_{1c}	2; 0/1/1 In low-risk diabetes participants [24] In older adults ≥65 years [40]	1; 0/0/1 In moderate- and high-risk diabetes participants [24]
Fasting glucose	2; 0/2/0 For high LIPA [30[a]], in older adults ≥65 years [40]	5; 2/3/0 [19, 20[a], 38[a], 49[a]], for low-LIPA [30[a]]
WC	8; 3/5/0 [19, 20[a], 22, 30[a], 38[a], 40, 49[a], 53[a]]	1; 0/1/0 For low LIPA [30[a]]
BMI	4; 1/3/0 [38[a], 40, 49[a]], for high LIPA [30[a]]	1; 0/1/0 For low LIPA [30[a]]
Triceps skinfold	2; 0/2/0 [38[a], 40]	–
Diabetes	1; 0/1/0 [20[a]]	–
Metabolic syndrome	3; 1/2/0 [20[a], 38[a]], for bouted LIPA [53[a]]	1; 1/0/0 For sporadic LIPA [53[a]]
Red blood cell distribution width	1; 0/1/0 [34[a]]	–
C-reactive protein	4; 1/3/0 [30[a], 38[a], 40, 49[a]]	1; 1/0/0 [19]
Non-alcoholic fatty liver disease		1; 0/1/0 [25]
BMD	1; 0/1/0 In women [21]	1; 0/1/0 In men [21]
Pain (low back pain and chronic widespread pain)	–	2; 0/0/2 [23, 54]
Balance	1; 0/1/0 [35]	–
Disability	1; 0/1/0 [52[a]]	–
Depression	2; 0/2/0 [32], in minimal depression [55]	–
Tinnitus	1; 0/1/0 [41]	–
Mortality	3; 2/1/0 [56[a], 57, 58[a]]	–

[a] References indicate those that adjusted for moderate to vigorous physical activity

LIPA light-intensity physical activity, *TAG* triglycerides, *HDL-C* high-density lipoprotein cholesterol, *HOMA-β (HOMA-%β)* homeostasis model assessment of β-cell function, *HOMA-S (HOMA-%S)* homeostasis model assessment of insulin sensitivity, *HOMA-IR* homeostasis model assessment of insulin resistance, *HbA1c* glycosylated hemoglobin, *WC* waist circumference, *BMI* body mass index, *BMD* bone mineral density

benefits, but, also, LIPA can bring meaningful improvements in depressive syndromes.

The results of our review are less consistent in diseased populations. For example, it is not clear why LIPA is beneficially associated with measures of adiposity in the general population and COPD patients, but not in cancer survivors. In addition, the pattern of beneficial associations in patients with diabetes (male vs. female, and younger vs. older) needs to be confirmed or refuted by further studies.

Only three longitudinal studies could be identified for our review, all examining the relationship between LIPA and mortality. The results were consistently positive and in line with those in another study of older men with a follow-up of 4.5 years [83], and with a large body of evidence linking even lower amounts of PA to reduced mortality risk [84–86].

4.2 Biological Mechanisms

LIPA seems to provide outcome-dependent and physiologically plausible beneficial health benefits, as supported by intervention studies [62–64, 66, 67, 72, 73, 76]. Because of the sparseness of experimental data to date, the underlying biological mechanisms cannot be fully explained. It seems that depending on the endpoint in question, PA-induced effects might not be driven by activity *intensity* per se. Accordingly, a wide range of exercise intensities has been found to yield the same effect on postprandial glycemia or insulinemia [87] and HDL cholesterol [67]. A further aspect to consider is that activities of lower intensities can be sustained for much longer periods of time than higher intensities. Activity *duration* has been suggested as one of the major factors that strongly influence activity-induced metabolic response. Glucose response [88] and insulin action [62, 63] after exercise training have been found to be affected more by duration than by intensity. Similarly, the results of the Studies of Targeted Risk Reduction Interventions through Defined Exercise (STRRIDE) suggest that volume of exercise, rather than its intensity, appears to make a greater difference to plasma lipoprotein concentrations [89]. Other outcomes, such as body weight, body composition and measures of obesity, seem to respond to PA in a dose-response manner, with benefits already starting to manifest themselves at low intensities [73]. Since total energy expenditure (rather than activity intensity) is essential in weight management, the overall effects of LIPA might protect against weight gain. Although more research is required to better understand how LIPA influences metabolic outcomes, the consistency of associations suggests a possible causal link. The cumulative cardiometabolic effects of LIPA might translate into survival benefits over the long term, as seen in the NHANES dataset.

Nonetheless, a nuanced view is warranted and LIPA should not to be regarded as a panacea. We found more data and stronger evidence for the beneficial effects of LIPA on markers of cardiometabolic health than on musculoskeletal health, including pain and function. Information from studies that subdivided the light-intensity range into lower and higher zones also suggest that there might be graded benefits across the whole PA intensity continuum. High LIPA was substantially more beneficial for cardiometabolic markers [30] and mortality risk reduction [56] than low LIPA. One can also argue that the health benefits of LIPA might be driven more by high LIPA than low LIPA, or, in other words, that there may be a minimal intensity threshold below which activities provide no quantifiable health benefits. This could also explain the finding that standing, which is LIPA, has not unequivocally been found to be beneficial [90]. The results of our review do not repudiate health effects of PA of moderate to high intensity, but add to our knowledge of health-relevant intensity ranges.

4.3 Strength and Limitations

Our review has strengths and limitations. The use of device-based methods of PA assessment in epidemiologic studies is relatively new. Our findings have to be seen in light of the limitations of the evidence base available. Accelerometry is regarded as an 'objective' and accurate method of PA assessment, yet interpreting data remains challenging. In the 2003/2004 and 2005/2006 NHANES waves, the ActiGraph 7164, a uniaxial motion sensor, was used. Uniaxial accelerometers cannot assess non-step-based activities and energy expenditure induced by upper body movement, load carrying or walking uphill. Triaxial models can measure movement in three dimensions. This fact has led to the current, not fully confirmed, assumption that triaxial devices can provide a more accurate assessment of PA [91, 92].

We used the NHANES database for our analysis to minimize discrepancies arising from various data sources using different methodologies. Our review shows that even using the very same database does not automatically guarantee the ability to make direct comparisons among studies. The different operationalization of PA ranges and the definitions of accelerometer wear time and valid days may compromise such an effort since different definitions of non-wear time and a valid day might affect study results. There is also limited knowledge as to what extent cut-off points established for healthy adults may or may not apply to all age groups and diseased populations. It has been suggested that, in adults, 3–5 valid days of accelerometer wear are necessary to reflect individuals' habitual PA [93]; however, this recommendation has been followed rather

inconsistently by researchers [12]. In the present review, four studies included participants with less than 4 days of accelerometer wear time. An important issue to consider is whether excluding participants with invalid accelerometer data due to, for example, an insufficient number of valid days might introduce a selection bias. Loprinzi and colleagues observed significant differences in demographic, behavioral, and biological variables between participants with and without valid accelerometer data, and concluded that excluding participants with invalid accelerometer data might limit generalizability [94]. However, one study included in our review found that results were not substantially different when including people with 1 or more days of monitor wear time versus 4 or more days [23]. These findings suggest that dealing with datasets of less than four valid accelerometer wear days is a complex issue. This might call for a case-by-case decision carefully weighing the pros and cons of more versus less accurate PA data and higher versus lower representativeness of study samples.

Of the 40 included studies, 13 adjusted for MVPA and only 5 adjusted for both MVPA and SB. For outcomes where several studies were available, we found no contradictory results between studies with and without adjustment for MVPA. Since relatively little is currently known about the health effects of LIPA, we conceptualised our analysis as a comprehensive approach and therefore did not exclude thematically relevant studies based solely on the one criterion of adjusting or not adjusting for MVPA.

The large majority of the studies identified were cross-sectional, limiting the ability to draw causal conclusions. Few data were available for some, and none at all for other, very important endpoints, such as cardiorespiratory and muscular fitness. Not all reports provided information on the validity of the instruments used.

To the best of our knowledge, this is the first systematic review to focus on the association between LIPA and modifiable health outcomes. We followed the rigorous PRISMA guidelines and conducted our literature search in four databases without language restriction. In order to minimize methodological diversity in the assessment of PA and the measurement of health outcomes, we focused on the NHANES dataset.

4.4 Findings in Relation to Current Recommendations and Future Research Directions

Current PA recommendations support the accumulation of 150 min of at least moderate-intensity PA per week [5]. The Australian Physical Activity Guidelines note that "more research is required to clarify the health effects of different frequencies, intensities, durations, and types of activity and SB, especially the overall contribution of light intensity to health outcomes" [95]. To the best of our knowledge, the only guidance on light-intensity activity is given by the American Diabetes Association [96].

Evidence on the health benefits of LIPA is growing but more work needs to be carried out. Further longitudinal observational studies as well as intervention trials in various populations with the major biomarkers as endpoints should provide further data on the relationship between LIPA and health. If these data corroborate information available to date, it would be timely to consider updating PA recommendations to also include light-intensity activity.

5 Conclusions

LIPA seems to be favorably associated with important health outcomes, such as obesity, markers of lipid and glucose metabolism, and mortality in the general population and in some diseased populations. Currently inactive or insufficiently active people should be encouraged to engage in PA of any intensity. Inclusion of LIPA in PA recommendations for this target group should at least be considered.

Compliance with Ethical Standards

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