



Muscle-strengthening physical activity is associated with cancer mortality: results from the 1998–2011 National Health Interview Surveys, National Death Index record linkage

Mohamamd Siahpush¹ · Paraskevi A. Farazi² · Hongmei Wang³ · Regina E. Robbins⁴ · Gopal K. Singh⁵ · Dejun Su¹

Received: 2 August 2018 / Accepted: 10 April 2019 / Published online: 19 April 2019
© Springer Nature Switzerland AG 2019

Abstract

Purpose To examine the association of muscle-strengthening activities (MSA) and cancer mortality.

Methods We pooled data from the 1998 to 2009 National Health Interview Survey (NHIS), which were linked to records in the National Death Index. Mortality follow-up was through 31 December 2011. Based on U.S. federal guidelines for physical activity, we dichotomized MSA and compared those who performed MSA twice a week or more to others with lower MSA. We also examined dose–response relationship of MSA frequency with cancer mortality. Hazard ratios (HR) from Cox regression were computed to estimate the association of MSA with the risk of cancer mortality. Mean follow-up was 7.9 years and the analysis sample size was 310,282.

Results Covariate-adjusted results showed that meeting the MSA guideline was associated with a 19% lower risk of cancer mortality (HR 0.81, 95% CI 0.73, 0.90). We found no evidence of a dose–response relationship between the frequency of performing MSA and cancer mortality.

Conclusion Adhering to the U.S. federal guideline for MSA is associated with lower cancer mortality. Public health programs and policy for cancer prevention and control should promote MSA to further reduce cancer mortality.

Keywords Muscle-strengthening physical activity · Cancer mortality · Guidelines for physical activity · National Health Interview Survey

✉ Mohamamd Siahpush
msiahpush@unmc.edu

Paraskevi A. Farazi
evi.farazi@unmc.edu

Hongmei Wang
hongmeiwang@unmc.edu

Regina E. Robbins
rrobbins@unomaha.edu

Gopal K. Singh
gsingh@hrsa.gov

Dejun Su
dejun.su@unmc.edu

² Department of Epidemiology, College of Public Health, University of Nebraska Medical Center, 984395 Nebraska Medical Center, Omaha, USA

³ Department of Health Services Research and Administration, College of Public Health, University of Nebraska Medical Center, 984395 Nebraska Medical Center, Omaha, USA

⁴ Department of Sociology & Anthropology, University of Nebraska at Omaha, 6001 Dodge Street, Omaha, NE 68182-0213, USA

⁵ Office of Health Equity, Health Resources and Services Administration, U.S. Department of Health & Human Services, Rockville, MD 20857, USA

¹ Department of Health Promotion, College of Public Health, University of Nebraska Medical Center, 984340 Nebraska Medical Center, Omaha, NE 68198-4340, USA

Introduction

Cancer is the second leading cause of death and is responsible for more than half a million or one in four deaths every year in the United States [1]. Modifiable risk factors for mortality from various types of cancer include cigarette smoking, alcohol use, poor diet, overweight and obesity, sun exposure, and insufficient physical activity [2–5]. While many studies have examined the association of aerobic physical activity and cancer mortality [4, 6–9], little attention has been given to muscle-strengthening activities (MSA) as a predictor of cancer mortality. Accordingly, the *2018 physical Activity Guidelines Advisory Committee*, which recommends that adults engage in MSA two or more days a week, has called for more research on the association between MSA and cancer [10].

To our knowledge, there are only four previous published studies that examine the effect of MSA on cancer mortality. None of these studies reported narrow enough confidence intervals (CIs) to conclude a protective effect on cancer mortality; however, all studies reported effect estimates whose sheer values were consistent with a protective effect. Kamada et al. investigated cancer mortality among a sample of 28,879 older women with an average age of 62.2 years and a mean follow-up of 12 years. They found that compared to women who performed no MSA, those who performed 1–59 min of MSA per week had a hazard ratio (HR) of 0.87 (95% CI 0.73, 1.05) and those who performed 60 or more minutes of MSA per week had an HR of 0.92 (95% CI 0.68, 1.24) [11]. Whereas Kamada et al.'s study focused on older women, Hsu et al. examined cancer mortality among older men. They used data from a sample of 1,705 men with an average age of 76.9 and a median follow-up of 7 years. They reported an HR of 0.66 (95% CI 0.33, 1.29) for those who engaged in any MSA compared to those who did not [12]. Another study was conducted by Loprinzi et al. who used data from a sample of 1,411 men and women aged between 20 and 85 years who had mobility limitations [13]. This cohort was followed for an average of 6.8 years. The authors reported an HR of 0.27 (95% CI 0.06–1.20) for those engaging in two or more sessions per week of MSA versus those engaging in less than that amount. Finally, Dankel et al. followed a sample of 2,773 men and women aged 50 years or older for an average of 9.7 years and reported that the HR associated with two or more MSA sessions per week versus less than that amount was 0.92 (95% CI 0.45–1.86) [14]. These studies either had a relatively small sample size or did not include the general population of adults. Despite their limitations, these studies have invariably reported HR values consistent with a protective effect on cancer mortality, which provided the motivation for the current study to use a large representative sample of adults and examine the

association of MSA with cancer mortality. Our aim was to combine samples from 12 years of the National Health Interview Survey (NHIS), which have been linked to the National Mortality Index, to examine the association of MSA and cancer mortality.

Methods

Data

We employed public use data from the NHIS files for the years 1998–2009 and the corresponding files with the linkage of NHIS and NDI provided by the National Center for Health Statistics (NCHS) [15]. The NHIS uses a multistage probability sampling design and is cross-sectional, conducted annually, and representative of the civilian non-institutional population of the U.S. The annual response rate in the years 1998–2009 ranged between 60.8% in 2005 and 74.3% in 2002. All data are based on self-reports and obtained via interviews in the homes of participants. Substantive and methodological details of the NHIS are described elsewhere [16, 17]. The NCHS has linked the survey participants for the years 1986–2009 to death certificate data from the NDI with follow-ups through 31 December 2011. Mortality ascertainment is based on a probabilistic matching algorithm that links the NHIS and NDI records by an individual's social security number, name, and other demographic variables [18]. We limited the analysis to individuals who were aged 18 years or older at the baseline. As shown in Table 1, the sample size in the period 1998–2009 was 350,771. Of these, 331,985 (94.6%) were eligible for linkage, meaning that they provided adequate information (e.g., social security number, name, birth date, race, and sex) in the interviews for matching with NDI records. Of these individuals, 310,628 (93.46%) were used in the final analysis sample, as described below. Institutional approval was not required for this study as it employed publically available secondary data.

Measurement

Mortality

The causes of death in the data were coded according to the tenth revision of International Classification of Diseases (ICD-10) [19]. The study outcome was mortality from all cancers combined defined as C00–C97 (malignant neoplasms). Follow-up time for individuals who died was measured in number of months from the month and year of interview to the month and year of death. Because quarter instead of month of death was available, we assumed that

Table 1 Sample size and number of cancer deaths by year

NHIS interview year	Adults aged ≥ 18	Met eligibility criteria for linkage to NDI	Used in the analysis ^a	Cancer deaths from interview through 31 December 2011
1998	32,440	30,577	29,097	1,148
1999	30,801	29,075	27,528	1,000
2000	32,374	30,593	28,775	903
2001	33,326	31,355	29,332	851
2002	31,044	28,995	26,946	698
2003	30,852	28,210	26,363	627
2004	31,326	29,192	27,191	586
2005	31,428	29,131	27,215	521
2006	24,275	23,419	21,551	316
2007	23,393	22,692	20,823	265
2008	21,781	21,362	19,949	204
2009	27,731	27,384	25,858	156
Total	350,771	331,985 ^b	310,628	7,275

^aThose with missing values for analysis time or any study variable except poverty status were excluded

^bDue to incomplete data, 21,357 of eligible participants were eliminated

deaths occurred in the middle of the recorded quarter, i.e., February, May, August, or November. As shown in Table 1, a total of 7,273 cancer deaths occurred during the follow-up period, which had a mean of 7.9 years.

MSA

Respondents were asked: “How often do you do leisure-time physical activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics?” From responses to this question, we computed a dichotomous variable indicating whether a respondent met the U.S. federal guideline [8] of performing strengthening exercises ≥ 2 times per week. In order to assess the presence of a dose–response relationship between MSA and cancer mortality, we recategorized MSA performance to zero, one, two, three, four, and five times or more often a week.

Covariates

The following covariates were included as possible confounders in regression models: minutes of aerobic physical activity per week, smoking status, body mass index (BMI), alcohol consumption, previous cancer diagnosis, presence of chronic condition, self-rated health, sex, age, marital status, race/ethnicity, nativity, poverty status, education, and survey year as a continuous variable.

Respondents were asked how often they performed “light or moderate leisure-time physical activities for at least 10 min that cause[d] only light sweating or a slight to moderate increase in breathing or heart rate” and “vigorous

leisure-time physical activities for at least 10 min that cause[d] heavy sweating or large increases in breathing or heart rate.” They were also asked “About how long do you do these light or moderate leisure-time physical activities [or vigorous physical activities] each time?” From these questions, we computed the length of time of moderate and vigorous aerobic physical activity in minutes per week.

Respondents were asked “Have you smoked at least 100 cigarettes in your entire life?” Those who replied affirmatively were then asked “Do you now smoke cigarettes every day, some days or not at all?” Based on these questions, we defined smoking status as having three categories: [6, 20, 21] (1) never smokers consisting of those who have not smoked more than a 100 cigarettes in their life; (2) former smokers consisting of those who have smoked more than a 100 cigarettes in their life but do not currently smoke; and (3) current smokers consisting of those who have smoked at least 100 cigarettes in their life and currently smoked every day or some days. BMI was computed as the ratio of self-reported weight in kilograms to the square of self-reported height in meters. We defined alcohol consumption as having three categories: [22–24] (1) lifetime abstainers consisting of those who have had less than 12 drinks in life; (2) former drinkers consisting of those who have had 12 or more drinks in life, but no drinks in the past year; and (3) current drinkers consisting of those who have had 12 or more drinks in life and one or more drinks in the past year.

Individuals who reported to have previously been diagnosed by a health professional with cancer were distinguished from others. Individuals who reported to have previously been diagnosed with diabetes, a heart attack, angina pectoris, coronary heart disease, heart condition,

hypertension, a stroke, emphysema, asthma, or chronic bronchitis were classified as having a chronic condition. Additionally, individuals who reported difficulty performing the following activities were considered also as having a chronic condition: carrying or lifting a 10-pound object; walking up 10 steps without resting; using fingers to grasp objects; reaching up over the head; standing for 2 h; sitting for 2 h; stooping, bending, or kneeling; walking a quarter of a mile; going out for activities such as shopping or seeing a movie; pushing or pulling large objects; relaxing at home or for leisure; and participating in social activities.

Self-rated health was dichotomized as fair or poor versus excellent, very good, and good. Age was used as a continuous variable. We defined marital status as having four categories: married, separated or divorced, widowed, and never married. Race/ethnicity was defined by four categories as non-Hispanic White, non-Hispanic Black, Hispanic, and other. Nativity distinguished those born in a U.S. state or District of Columbia from others. Family poverty status was measured as the ratio of total family income from all sources before taxes to the U.S. Census Bureau's poverty thresholds for each survey year [25]. Educational attainment was grouped into three categories: less than high school diploma, high school diploma and some college, and college degree.

Statistical analyses

The data for all the 12 survey years, i.e., 1998–2009, along with information about mortality outcomes were pooled. Cox proportional hazards regression was used to model time to death as a function of MSA and covariates and to report HRs. In the analyses, individuals who did not die of cancer as well as those surviving at the end of the follow-up were right censored. In all analyses, we adjusted for the complex sampling design of the NHIS by taking into account sampling weights provided in the NHIS-NDI-linked mortality files, stratification, and primary sampling units in computations. We adjusted the sampling weights by multiplying the original weight in a given survey to the ratio of the sample size for that survey and the sum of samples sizes of all 12 surveys [26]. Cases with missing values for any of the study variables (i.e., 6.5% of the sample) except poverty status were excluded from the analysis. Missing values for poverty status (19.6%) were included as a distinct category. Variables with a *p* value of greater than 0.1 in bivariate analyses were not included in multivariable models. We examined the interaction of sex, age, and previous cancer diagnosis with MSA in their effects on cancer mortality risk and found no evidence of such interaction. We used Stata version 14.1 for all analyses [27].

Results

Table 2 provides sample characteristics. About 20.4% of the sample met the MSA physical activity guidelines, i.e., engaged in MSA activities two or more times a week. Respondents performed an average of 98.2 min of moderate and 59 min of vigorous physical activity per week. About 42% of the sample met the aerobic physical activity guidelines.

Table 3 provides unadjusted and adjusted HRs for the association of meeting MSA guidelines and level of MSA with cancer mortality. Adjusted results controlled for moderate physical activity, vigorous physical activity, smoking status, BMI, alcohol consumption, previous cancer diagnosis, chronic condition, self-rated health, sex, age, marital status, race/ethnicity, nativity, poverty status, education, and year of survey. We focus on adjusted results to summarize the associations. Meeting MSA guidelines was associated with a 19% lower risk of cancer mortality (HR 0.81, 95% CI 0.73, 0.90). Furthermore, compared to no MSA, 1 day a week of MSA did not provide a cancer mortality benefit (HR 0.89; 95% CI 0.70, 1.12). However, two (HR 0.77; 95% CI 0.63, 0.95), three (HR 0.82; 95% CI 0.70, 0.96), four (HR 0.71; 95% CI 0.53, 0.95), and five or more days (HR 0.84; 95% CI 0.73, 0.96) a week of MSA, compared to no MSA were associated with a lower probability of cancer mortality. There was no evidence of a dose–response relationship. These results did not change appreciably when we conducted sensitivity analyses and excluded individuals with a prior cancer diagnosis, those who could not reasonably perform MSA, and those who died within 2 years of their data collection interview.

Discussion

This prospective study of a large nationally representative sample showed that meeting the U.S. federal guidelines for MSA, i.e., engaging in MSA at least twice per week, is associated with a lower risk of cancer mortality. We found no evidence of a dose–response relationship. These results held when we excluded individuals with cancer diagnosis, those who could not reasonably engage in MSA, and those who died within 2 years of their data collection interview. This was the first study to show an association between MSA and cancer mortality. Previous studies that examined this association reported null findings [11–14]. The discrepancy between our findings and those of the previous studies likely is because they either used a small sample size [12] or limited their samples to older individuals [11, 13, 14].

There are several biological mechanisms that could be responsible for the association of MSA and cancer risk or

Table 2 Weighted sample characteristics according to whether individuals met muscle-strengthening activity (MSA) guidelines ($n = 310,628$)

Variable	Did not meet MSA guidelines ($n = 250,835$) % or mean (SE ^a)	Met MSA guide- lines ($n = 59,793$) % or mean (SE ^a)
Minutes of moderate physical activity p/w	98.17 (0.91)	189.02 (1.96)
Minutes of vigorous physical activity p/w	59.00 (0.72)	203.73 (1.73)
Smoking status		
Never smoker	54.41	60.12
Former smoker	22.23	22.62
Current smoker	23.36	17.26
BMI	27.28 (0.02)	26.05 (0.03)
Alcohol consumption		
Lifetime abstainer	24.53	13.43
Former drinker	15.94	10.03
Current drinker	59.53	76.55
Previous cancer diagnosis		
Yes	7.51	5.76
No	92.49	94.24
Chronic condition		
Yes	16.86	6.49
No	83.14	93.51
Self-rated health		
Fair/poor	14.07	4.66
Good/very good/excellent	85.93	95.34
Sex		
Male	46.81	56.21
Female	53.19	43.79
Age, years	46.52 (0.08)	40.52 (0.12)
Marital status		
Married	58.69	53.32
Divorced/separated	12.93	11.65
Widowed	7.34	3.24
Never married	21.04	31.8
Race/ethnicity		
Non-hispanic white	71.19	75.98
Non-hispanic black	11.53	10.67
Hispanic	12.59	8.78
Other	4.7	4.57
Nativity		
Born in a U.S. state or DC	84.49	89.65
Other	15.51	10.35
Poverty status		
< 100%	9.88	6.65
≥ 100% and < 200%	15.45	9.64
≥ 200% and < 300%	14.22	11.88
≥ 300% and < 400%	11.41	11.92
≥ 400%	28.56	43.75
No income information	20.48	16.17
Education		
Less than high school diploma	16.63	6.37
High school diploma/some college	61.72	56.35
College degree	21.65	37.29

*Standard error of the mean

Table 3 Hazard ratios (HR) and 95% confidence intervals (CI) for the association of meeting muscle-strengthening activity (MSA) guidelines and frequency of MSA with total cancer mortality ($n = 310,628$)

Covariates	Unadjusted HR (95% CI)	<i>p</i> value	Adjusted ^a HR (95% CI)	<i>p</i> value
Meeting MSA guidelines		<0.001		<0.001
Yes	0.43 (0.39, 0.47)		0.81 (0.73, 0.89)	
No	1.00		1.00	
Frequency of MSA (times per week)		<0.001		0.002 ^b
0	1.00		1.00	
1	0.33 (0.26, 0.42)		0.89 (0.70, 1.12)	
2	0.33 (0.27, 0.40)		0.77 (0.63, 0.95)	
3	0.39 (0.34, 0.45)		0.82 (0.70, 0.95)	
4	0.28 (0.21, 0.37)		0.71 (0.53, 0.95)	
5+	0.58 (0.51, 0.67)		0.84 (0.73, 0.96)	

^aBoth models adjust for the effect of minutes of moderate physical activity, minutes of rigorous physical activity, smoking status, BMI, previous cancer diagnosis, chronic condition, self-rated health, sex, age, marital status, race/ethnicity, nativity, poverty status, and education

^bThe *p* value corresponds to the adjusted association of MSA as a categorical variable

progression [28–31]. Many of these mechanisms may act through the effect of physical activity on body fat and the resulting changes to circulating adipokines and cytokines, insulin resistance, blood insulin levels, and sex hormone production, which are associated with cancer risk [28]. Another mechanism could be through the effect of MSA on increased skeletal muscle mass, which results in reduced insulin resistance and hyperinsulinemia, independent of body fat [29, 32, 33]. Furthermore, physical activity might reduce systemic inflammation which is responsible for an increased risk of cancer, although studies on this topic have examined aerobic activities, not MSA [34–37]. It is also possible that the anxiolytic effects of MSA [38] can reduce the level of stress-related psychosocial risk factors that are associated with higher cancer incidence, poorer survival in patients with diagnosed cancer, and higher cancer mortality [39, 40]. Additionally, it is hypothesized that physical activity could increase the number of natural killer cells, which retard tumor growth [41]. Finally, the association of MSA with reduced mortality could be due to the fact that muscle strength is associated with lower functional limitations in activities of daily living [42, 43], which in turn is linked to lower cancer mortality [44, 45].

The main strength of this study was that it utilized pooled data from large nationally representative samples with high response rates and a data collection based on in-person interviews. The study had several limitations. First, we were unable to assess changes in MSA practices of respondents during the follow-up period; thus, we assumed that the exposure was time invariant. Second, the measurement of MSA was crude. We only had information on leisure-time MSA. Much MSA can occur at a person's occupation, especially among manual workers. Controlling

for occupation in our regression models would have been helpful to address occupational variations in MSA, but our data lacked adequately consistent occupational measures across the survey years we employed in the analysis. Our measurement of MSA also did not include information on the muscles involved in MSA, and intensity, type, and duration of MSA. This information is important because the federal guidelines for physical activity indicates that MSA should be moderate or high intensity and involve all major muscle groups [10]. Third, due to small numbers of death from site-specific cancers, we were unable to examine the association of MSA with mortality from different types of cancer. Fourth, we did not have data on family history of cancer across all the survey years and thus we were unable to control for genetic predispositions to cancer in our analysis. Fifth, we did not have data on and were unable to control for diet, which is shown to be associated with many cancers [46, 47]. Sixth, the association between MSA and cancer mortality could be due to reverse causation, with lack of MSA being the consequence of having cancer or ill health resulting from cancer. However, we were to some extent able to account for reverse causality by controlling for prior diagnosis of cancer, presence of a chronic condition, and self-rated health. Finally, NDI has biases in identifying deaths among females versus males and non-Whites versus Whites. In the case of females, the bias arises because many of them change their surnames after marriage. In the case of non-Whites, the bias is because of incorrect spelling or reporting of ethnic names and that non-Whites are less likely to report their social security numbers. [48].

By showing that MSA reduces the risk of cancer mortality, this research has added to the body of literature on the

modifiable risk factors for cancer. The American Cancer Society currently recommends aerobic physical activity for cancer prevention [49]. They and other agencies that promote cancer prevention and control can use the results of this research to promote MSA and highlight that engaging in MSA twice a week is a protective factor against cancer mortality over and above the effect of aerobic exercise. Furthermore, given that the association of MSA with cancer mortality holds regardless of whether or not an individual has a chronic condition (including a disability that may limit mobility) or had a prior cancer diagnosis, clinicians may consider promoting MSA, in addition to aerobic exercise, among their patients with chronic conditions or who are cancer survivors.

Funding This study was not funded by any grants or funding agencies.

Data availability Secondary data that are publically available were used in this paper.

Compliance with ethical standards

Conflicts of interest There are no conflict of interest.

References

- Centers for Disease Control and prevention (2018) Cancer Prevention and Control. U.S. Department of Health and Human Services. <https://www.cdc.gov/cancer/dpcp/data/types.htm>. Accessed May 2018
- World Health Organization (2011) Global status report on noncommunicable diseases 2010. World Health Organization, Geneva
- Islami F, Goding SA, Miller KD, Siegel RL, Fedewa SA, Jacobs EJ, McCullough ML, Patel AV, Ma J, Soerjomataram I (2018) Proportion and number of cancer cases and deaths attributable to potentially modifiable risk factors in the United States. *Cancer J Clin* 68(1):31–54
- Danaei G, Ding EL, Mozaffarian D, Taylor B, Rehm J, Murray CJ, Ezzati M (2009) The preventable causes of death in the United States: comparative risk assessment of dietary, lifestyle, and metabolic risk factors. *PLoS Med* 6(4):e1000058
- Vineis P, Wild CP (2014) Global cancer patterns: causes and prevention. *Lancet* 383(9916):549–557
- O'Donovan G, Hamer M, Stamatakis E (2017) Relationships between exercise, smoking habit and mortality in more than 100,000 adults. *Int J Cancer* 140(8):1819–1827. <https://doi.org/10.1002/ijc.30611>
- Laukkanen JA, Rauramaa R, Mäkikallio T, Toriola AT, Kurl S (2011) Intensity of leisure-time physical activity and cancer mortality in men. *Br J Sports Med* 45(2):125–129
- 2018 Physical Activity Guidelines Advisory Committee (2018) 2018 Physical Activity Guidelines Advisory Committee Scientific Report. U.S. Department of Health and Human Services
- Hu G, Tuomilehto J, Silventoinen K, Barengo NC, Peltonen M, Jousilahti P (2005) The effects of physical activity and body mass index on cardiovascular, cancer and all-cause mortality among 47 212 middle-aged Finnish men and women. *Int J Obes* 29(8):894
- U.S. Department of Health and Human Services (2018) Physical Activity Guidelines for Americans, 2nd edition, vol U.S. Department of Health and Human Services. Washington, DC
- Kamada M, Shiroma EJ, Buring JE, Miyachi M, Lee IM (2017) Strength training and all-cause, cardiovascular disease, and cancer mortality in older women: a cohort study. *J Am Heart Assoc* 6(11):e007677
- Hsu B, Merom D, Blyth FM, Naganathan V, Hirani V, Le Couteur DG, Seibel MJ, Waite LM, Handelsman DJ, Cumming RG (2018) Total physical activity, exercise intensity, and walking speed as predictors of all-cause and cause-specific mortality over 7 years in older men: the Concord Health and Aging in Men Project. *J Am Med Direct Assoc* 19(3):216–222
- Loprinzi PD, Addoh O, Mann JR (2017) Association between muscle strengthening physical activities and mortality among American adults with mobility limitations. *Prev Med* 99:207–210
- Dankel SJ, Loenneke JP, Loprinzi PD (2018) Cancer-specific mortality relative to engagement in muscle-strengthening activities and lower extremity strength. *J Phys Act Health* 15(2):144–149
- Blewett LA, Rivera Drew JA, Griffin R, King ML, Williams KCW (2016) IPUMS Health Surveys: National Health Interview Survey, version 6.2. <http://doi.org/10.18128/D070.V6.2>
- Botman S, Moriarity CL (2000) Design and estimation for the national health interview survey, 1995–2004, vol 2. National Center for Health Statistics, Hyattsville
- Parsons VL, Moriarity CL, Jonas K, Moore TF, Davis KE, Tompkins L (2014) Design and estimation for the national health interview survey, 2006–2015, vol 2. National Center for Health Statistics, Hyattsville
- National Center for Health Statistics (2009) The National Health Interview Survey (1986–2004) linked mortality files, mortality follow-up through 2006: matching methodology. National Center for Health Statistics, Hyattsville
- World Health Organization (1993) The ICD-10 classification of mental and behavioural disorders: diagnostic criteria for research. World Health Organization, Geneva
- Hedblad B, Ogren M, Isacson S-O, Janzon L (1997) Reduced cardiovascular mortality risk in male smokers who are physically active: results from a 25-year follow-up of the prospective population study men born in 1914. *Arch Intern Med* 157(8):893–899
- Thun MJ, Carter BD, Feskanich D, Freedman ND, Prentice R, Lopez AD, Hartge P, Gapstur SM (2013) 50-year trends in smoking-related mortality in the United States. *N Engl J Med* 368(4):351–364
- Liang W, Chikritzhs T (2013) The association between alcohol exposure and self-reported health status: the effect of separating former and current drinkers. *PLoS ONE* 8(2):e55881
- French MT, Zavala SK (2007) The health benefits of moderate drinking revisited: alcohol use and self-reported health status. *American Journal of Health Promotion* 21(6):484–491
- Bellizzi KM, Rowland JH, Jeffery DD, McNeel T (2005) Health behaviors of cancer survivors: examining opportunities for cancer control intervention. *J Clin Oncol* 23(34):8884–8893
- U.S. Census Bureau (2016) Poverty thresholds. U.S. Census Bureau. <https://www.census.gov/data/tables/time-series/demo/income-poverty/historical-poverty-thresholds.html>. Accessed 2 May 2017
- Korn EL, Graubard BI (1999) Analysis of health surveys. John Wiley & Sons, New York
- StataCorp (2015) Stata Statistical Software: release 14.1, MP Parallel Edition, vol Book, Whole. StataCorp LP, College Station
- McTiernan A (2008) Mechanisms linking physical activity with cancer. *Nat Rev Cancer* 8(3):205

29. Friedenreich CM, Neilson HK, Lynch BM (2010) State of the epidemiological evidence on physical activity and cancer prevention. *Eur J Cancer* 46(14):2593–2604. <https://doi.org/10.1016/j.ejca.2010.07.028>
30. Rogers CJ, Colbert LH, Greiner JW, Perkins SN, Hursting SD (2008) Physical activity and cancer prevention: pathways and targets for intervention. *Sports Med* 38(4):271–296
31. Clague J, Bernstein L (2012) Physical activity and cancer. *Cur Oncol Rep* 14(6):550–558. <https://doi.org/10.1007/s11912-012-0265-5>
32. Frank LL, Sorensen BE, Yasui Y, Tworoger SS, Schwartz RS, Ulrich CM, Irwin ML, Rudolph RE, Rajan KB, Stanczyk F, Bowen D, Weigle DS, Potter JD, McTiernan A (2005) Effects of exercise on metabolic risk variables in overweight postmenopausal women: a randomized clinical trial. *Obes Res* 13(3):615–625. <https://doi.org/10.1038/oby.2005.66>
33. Boule NG, Haddad E, Kenny GP, Wells GA, Sigal RJ (2001) Effects of exercise on glycemic control and body mass in type 2 diabetes mellitus: a meta-analysis of controlled clinical trials. *JAMA* 286(10):1218–1227
34. Il'yasova D, Colbert LH, Harris TB, Newman AB, Bauer DC, Satterfield S, Kritchevsky SB (2005) Circulating levels of inflammatory markers and cancer risk in the health aging and body composition cohort. *Cancer Epidemiol Biomarkers Prev* 14(10):2413–2418. <https://doi.org/10.1158/1055-9965.Epi-05-0316>
35. Hamer M, Sabia S, Batty GD, Shipley MJ, Tabak AG, Singh-Manoux A, Kivimaki M (2012) Physical activity and inflammatory markers over 10 years: follow-up in men and women from the Whitehall II cohort study. *Circulation* 126(8):928–933. <https://doi.org/10.1161/circulationaha.112.103879>
36. Lakka TA, Lakka H-M, Rankinen T, Leon AS, Rao D, Skinner JS, Wilmore JH, Bouchard C (2005) Effect of exercise training on plasma levels of C-reactive protein in healthy adults: the HERITAGE Family Study. *Eur Heart J* 26(19):2018–2025
37. Camhi SM, Stefanick ML, Ridker PM, Young DR (2010) Changes in C-reactive protein from low-fat diet and/or physical activity in men and women with and without metabolic syndrome. *Metabolism* 59(1):54–61
38. Strickland JC, Smith MA (2014) The anxiolytic effects of resistance exercise. *Front Psychol* 5:753. <https://doi.org/10.3389/fpsyg.2014.00753>
39. Chida Y, Hamer M, Wardle J, Steptoe A (2008) Do stress-related psychosocial factors contribute to cancer incidence and survival? *Nat Clin Pract Oncol* 5(8):466–475. <https://doi.org/10.1038/nconci1134>
40. Moreno-Smith M, Lutgendorf SK, Sood AK (2010) Impact of stress on cancer metastasis. *Fut Oncol (London, England)* 6(12):1863–1881. <https://doi.org/10.2217/fon.10.142>
41. McTiernan A (2016) Cancer prevention and management through exercise and weight control. CRC Press, New York
42. Brill PA, Macera CA, Davis DR, Blair SN, Gordon N (2000) Muscular strength and physical function. *Med Sci Sports Exerc* 32(2):412
43. Rantanen T, Guralnik JM, Foley D, Masaki K, Leveille S, Curb JD, White L (1999) Midlife hand grip strength as a predictor of old age disability. *JAMA* 281(6):558–560
44. Saquib N, Pierce JP, Saquib J, Flatt SW, Natarajan L, Bardwell WA, Patterson RE, Stefanick ML, Thomson CA, Rock CL (2011) Poor physical health predicts time to additional breast cancer events and mortality in breast cancer survivors. *Psycho-Oncology* 20(3):252–259
45. Stommel M, Given BA, Given CW (2002) Depression and functional status as predictors of death among cancer patients. *Cancer* 94(10):2719–2727
46. Research WCRFAIFC (2007) Food, nutrition, physical activity, and the prevention of cancer: a global perspective. AICR, Washington DC
47. Kushi LH, Doyle C, McCullough M, Rock CL, Demark-Wahnefried W, Bandera EV, Gapstur S, Patel AV, Andrews K, Gansler T (2012) American Cancer Society Guidelines on nutrition and physical activity for cancer prevention: reducing the risk of cancer with healthy food choices and physical activity. *Cancer J Clin* 62(1):30–67
48. National Center for Health Statistics (2013) National death index. Centers for Disease Control and Prevention, Hyattsville
49. American Cancer Society (2019) Diet and physical activity: what's the cancer connection? American Cancer Society. <https://www.cancer.org/cancer/cancer-causes/diet-physical-activity/diet-and-physical-activity.html>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.