Comparison of pre-diagnosis physical activity and its correlates among lung, breast, colorectal and prostate cancer patients: accelerometer data from the UK Biobank prospective cohort

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Abstract

Purpose Understanding pre-diagnosis physical activity (PA) and its correlates will be helpful in promoting PA. However, few studies have examined the actual volume and correlates of objectively measured pre-diagnosis PA and little is known about how PA behaviors are similar/different between cancer types. This study aimed to compare pre-diagnosis PA and its correlates in patients with lung cancer and other types of cancer (breast, colorectal, and prostate cancer) and examine the relationship between pre-diagnosis PA and all-cause mortality.

Methods This study used data from the UK Biobank, which is a national cohort study with accelerometry data. We included 2,662 participants and used adjusted linear regressions and survival analyses.

Results Male and female lung cancer groups spent a mean of 78 and 91 minutes/day in pre-diagnosis MVPA, respectively; this is lower than the three other types of cancer (P<0.001). Younger age and faster walking pace had a strong association with PA in all the four types of cancer (P<0.01). Smoking status had a strong association with PA in the lung cancer group, while obesity had a strong association with PA in breast, colorectal and prostate cancer (P<0.01). Higher levels of pre-diagnosis MVPA (≥1.5 hour/day) were associated with a significantly lower all-cause mortality risk.

Conclusions Our study suggests that lung cancer patients are the most inactive population before diagnosis. The identified difference in correlates of PA suggesting that cancer-specific approaches are needed in PA research and practices. This study also highlights the importance of high PA for individuals with high cancer risk.

1. Introduction

Physical activity (PA) provides numerous health benefits for cancer patients. Physical activity improves health outcomes including cardiovascular fitness, muscle strength, cancer-related fatigue, health-related quality of life, and depression [1–3]. Physical activity guidelines for cancer survivors recommend at least 150 minutes of moderate PA per week [4]. However, only 8%-58% of cancer survivors meet the PA recommendations [5–8]. Much work remains to be done to determine how best to improve PA among cancer patients [9].

Physical activity promotion could be implemented throughout the cancer diagnosis and survivorship continuum. The PA and Cancer Control (PACC) framework proposes six cancer-related time periods: two pre-diagnosis (pre-screening and screening) and four post-diagnosis (pre-treatment, treatment, survivorship, and end of life) [10]. Most existing research focuses on PA during the post-diagnosis period (e.g., before surgery/chemotherapy, during chemotherapy and after surgery/chemotherapy); less is known about pre-diagnosis PA. It is well established that a higher pre-diagnosis PA is associated with reduced overall/cancer-specific mortality among breast, colorectal, prostate, and lung cancer patients [9, 11–14] and higher pre-diagnosis PA is a strong predictor of post-diagnosis PA [15–17]. However, less is known about the actual volume of pre-diagnosis PA and its correlates. Cancer diagnosis is a “Teachable Moment” [18, 19]; understanding pre-diagnosis PA and its correlates will be helpful in identifying patients with high risk of physical inactivity.

Lung cancer is the second most common cancer and the leading cause of cancer-related death worldwide [20]. However, individuals with lung cancer are understudied compared with breast, colorectal, and prostate cancer [2]. A systematic review synthesized evidence regarding the factors influencing PA in lung cancer survivors and the findings were derived mainly from qualitative studies or quantitative studies with self-reported PA measures [21]. Self-reported data is subject to response bias (e.g., imprecise recall, influence of social desirability) [22] and is less accurate compared to data obtained using objective measures such as accelerometers [23]. Research is needed to examine pre-diagnosis PA behaviors using objective measures in lung cancer patients to characterize their PA features compared to patients with other cancer types (e.g., breast, colorectal and prostate cancer). This information will be helpful in determining if the same approach to promote PA is appropriate for all cancer types, or if a cancer specific approach is needed.

Several socio-demographic and health-related characteristics have been identified as correlates of PA in cancer survivors (e.g., younger age, lower BMI, fewer comorbidities) [24–27], but few studies compared patients with different types of cancer using the same sampling frame and measures. To our knowledge, only a few studies compared PA correlates, but they focused on post-diagnosis PA among breast, colorectal and prostate cancer patients and used self-reported PA measures [6, 15]. Less is known about PA features of lung cancer patients, compared to other cancer patients. To fill in this research gap, we conducted a secondary analysis of the accelerometer data from a national cohort study (UK Biobank). The aims were to: 1) compare pre-diagnosis PA of patients with lung cancer to patients with other types of cancer (breast, colorectal, and prostate cancer); 2) compare correlates of pre-diagnosis PA between patients with lung cancer and other types of cancer; and 3) examine the relationship between pre-diagnosis PA and all-cause mortality after lung, breast, colorectal and prostate cancer diagnosis.

2. Methods

2.1 Data source and participants

This study used data collected from the UK Biobank, which is a national cohort study in the UK. Demographic and health-related data were collected from 500,000 participants (aged 40–69 years) between 2006 and 2010, with a reassessment of 20,000 participant between 2012 and 2013 (the most recent data were used, this is referred to as baseline data for the purpose of this current study). Between 2013 and 2015, participants were re-contacted and invited to wear an accelerometer (Axivity AX3 wrist-worn triaxial accelerometer) if they provided a valid email address at the baseline assessment. Of the total recruited 500,000 UK Biobank sample, 236,519 participants were asked to join the accelerometer study to obtain objectively measured PA data under free-living conditions. A total of 106,053 agreed to wear a PA monitor (response rate to invitations = 44.8%) and 103,720 participants returned data between 2013 and 2015 [28]. Data from cancer and death registries were linked to the UK Biobank cohort to provide information on cancer diagnoses and death. The UK Biobank protocol was approved by the North West Multicenter Research Ethics Committee.

We included participants if they: 1) were diagnosed with primary lung cancer, breast cancer, colorectal cancer or prostate cancer after completing accelerometer data collection (see Supplemental Table 1 for ICD 9 and ICD 10 codes); 2) had valid accelerometer data (≥ 3 days of wear time) [28]; 3) had no missing values for socio-demographic and health-related variables (see below). A total of 2,662 participants were included (lung cancer = 248, breast cancer = 858, colorectal cancer = 451, prostate cancer = 1,105) (see Fig. 1 for details).

2.2 Measures

Physical activity was collected with the Axivity AX3 wrist worn triaxial accelerometer between 2013 and 2015. The participants were instructed to do the following: 1) start wearing the accelerometer device immediately after receiving it, 2) wear it for seven continuous days on their dominant wrist, 3) carry on with their normal activities, and 4) mail the device back to the research center, in a pre-paid envelope, after the seven-day monitoring period [28]. The raw accelerometer data were calibrated, and wear-time periods were identified using the UK Biobank preprocessing methods described by Doherty et al. [28]. Accelerometer-based summary measures in the dataset included the total mean acceleration/24 hours (vector magnitude in milligravity units = mg) and time spent in sedentary, light, and moderate-to-vigorous PA (MVPA). The proportion of time spent in moderate and vigorous PA was defined as the proportion of time spent in accelerations of 101–425 and > 425 milligravity, respectively [28–31].

Health-related factors were collected at baseline (2006–2010 and 2012–2013). (1) Self-reported overall health was rated as excellent, good, fair, or poor. (2) Self-reported comorbidities were measured using a 13-item comorbidity check list. For the purposes of this research, we analyzed data from patients with the most common cardiovascular and pulmonary comorbidities (heart attack, angina, stroke, hypertension, COPD, and asthma) and diabetes. The number of comorbidities ranged from 0 to 7. (3) Self-reported walking pace was measured using an item “How would you describe your usual walking pace?” with response options of slow, steady/average, or brisk. Participants could access further information which defined a slow pace as less than 3 miles per hour, a steady/average pace as between 3–4 miles per hour, and a brisk pace as more than 4 miles per hour. (4) Grip strength was assessed in each hand using a hydraulic hand dynamometer (Jamar J00105, Lafayette, IN, USA), which can measure isometric grip force up to 90 kilograms [32]. Grip strength was measured in both hands and the highest value was used for analyses. (5) Self-reported anxiety and depression was measured using a short version of the Patient Health Questionnaire (PHQ-9) and Generalized Anxiety Disorder [33–35]. Participants were asked “How often have you felt down, depressed, or hopeless”, “How often have you had little interest or pleasure in doing things”, “How often have you felt tense, fidgety or restless” and “How often have you felt tired or had little energy” over the past two weeks, with response options of “not at all = 1”, “several days = 2”, “more than half the days = 3” and “nearly every day = 4”. Scores ranged from 4 to 16, in which higher scores indicated more severe symptoms.

Socio-demographic characteristics were collected at baseline (2006–2010 and 2012–2013), including age, sex, ethnicity (white/non-white), Townsend Index of deprivation (high scores indicated higher levels of socioeconomic deprivation) [36], body mass index (BMI, underweight/normal/overweight/obese), smoking status (never/previous/current smoker), and alcohol drinking frequency (≤ 1–3 times/month, 1–4 times/week, daily or almost daily).

Date of cancer diagnosis and death were linked to the UK Biobank dataset. The included participants were diagnosed with lung/breast/colorectal/prostate cancer between 2013 and 2020 (at 4 days-6.5 years after accelerometer data collection). We followed

participants from their date of cancer diagnosis to their date of death as provided by UK Biobank's linkage to death registration data or to the latest follow-up date for mortality data (2021/3/21) if they did not have a death record.

2.3 Data analysis

Stata SE 17.0 software was used for data analysis. Descriptive statistics (percentages for categorical variables and mean and standard deviation for continuous variables) were calculated for socio-demographic, health-related characteristics, and accelerometer-measured PA in each type of cancer, stratified by gender. We compared the socio-demographic, health-related characteristics, and accelerometer-measured PA among different cancer groups stratified by gender. Chi-square tests of independence were used for categorical variables and ANOVA tests were used for continuous variables. A *P*-value of less than 0.01 was considered statistically significant for all analyses.

To address the three study aims (see Introduction section), we used linear regressions and survival analyses. Aim 1: Linear regression was used to compare time spent in MVPA between patients with lung cancer and other types of cancer, stratified by gender (independent variable = type of cancer; dependent variable = MVPA). The linear regression models included both unadjusted and adjusted estimates that control for socio-demographic characteristics. The unadjusted and adjusted coefficients and 95% confidence intervals (95% CI) were reported.

Aim 2: Linear regressions were used to examine the correlates of PA for each type of cancer (independent variable = gender, age, race, Townsend Index of Deprivation, BMI, smoking status, Alcohol drinking frequency, overall health rating, number of comorbidities, walking pace, grip strength, and anxiety and depression; dependent variable = MVPA). The linear regression models included both unadjusted and adjusted estimates that control for other socio-demographic and health-related characteristics. The unadjusted coefficients, adjusted coefficients, 95% CI, and adjusted standardized coefficient and were reported.

Aim 3: Survival analyses (Cox regressions) were used to assess the potential impact of time spent in MVPA on all-cause mortality. We used Cox regressions to model time-to-death as a function of time spent in MVPA per day and controlled for socio-demographics, cancer types and comorbidities. The unadjusted and adjusted Hazard Ratio (HR) and 95% CI for all-cause mortality were reported. Interaction analysis was performed to explore whether cancer types modified the association between MPVA and all-cause mortality.

3. Results

3.1 Characteristics of participants

A total of 2,662 participants were included in this study; they developed lung, breast, colorectal or prostate cancer after accelerometry data collection and met other criteria for inclusion. Participants in the lung cancer group were more likely to be current smokers and report brisk walking pace, compared to people with other types of cancer ($P < 0.01$). In addition, participants in the female lung cancer group were older than breast cancer and female colorectal cancer groups ($P < 0.001$). Participants in the male lung cancer group reported less frequent alcohol consumption, worse overall health, and more comorbidities and had lower grip strength, compared to prostate cancer and male colorectal cancer groups ($P < 0.01$) (see Table 1 for detail).

Table 1
Description of study population by tumor type (stratified by gender) (n = 2,662)

	Female				Male			
Characteristics	Lung (n = 129)	Breast (n = 858)	Colorectal (n = 194)	*P* value[a]	Lung (n = 119)	Prostate (n = 1,105)	Colorectal (n = 257)	*P* value[b]
Socio-demographics								
Age at accelerometer study, mean (SD)	66.09 (5.81)	62.82 (7.50)	65.74 (6.59)	< 0.001	68.44 (5.89)	67.95 (5.66)	66.94 (6.50)	< 0.05
Age at cancer diagnosis, mean (SD)	68.81 (5.96)	65.33 (7.64)	68.25 (6.77)	< 0.001	71.32 (5.97)	69.72 (5.64)	69.52 (6.82)	< 0.05
White race, %	97.67	97.44	96.91	0.894	97.48	97.92	98.83	0.571
Townsend Index of deprivation, mean (SD)	-0.96 (3.12)	-1.71 (2.73)	-1.41 (3.02)	< 0.05	-1.31 (3.13)	-2.05 (2.60)	-1.78 (2.78)	< 0.01
BMI, %	0.78	0.93	1.03	0.226	0.00	0.09	0.00	< 0.05
Underweight								
Normal	35.66	40.79	39.18		23.53	27.15	24.51	
Overweight	35.66	40.09	36.60		42.86	53.57	52.53	
Obese	27.91	18.18	23.20		33.61	19.19	22.96	
Smoking status, %				< 0.001				< 0.001
Never	27.13	57.46	45.88		15.97	48.05	45.91	
Previous	60.39	36.25	51.03		58.82	46.06	44.36	
Current	22.48	6.29	3.09		25.21	5.88	9.73	
Alcohol drinking frequency, %				0.143				< 0.01
≤1–3 times/month	37.21	29.37	36.08		27.73	16.20	14.01	
1–4 times/week	41.09	49.18	41.75		41.18	52.94	48.64	
Daily or almost daily	21.71	21.45	22.16		31.09	30.86	37.35	
Health-related characteristics								
Overall health rating, %				< 0.05				< 0.001
Excellent	10.85	19.93	20.10		10.08	21.54	16.73	
Good	63.57	64.69	64.43		50.42	60.54	61.09	
Fair	18.60	12.94	13.40		32.77	16.65	19.46	
Poor	6.98	2.45	2.06		6.72	1.27	2.72	
No. of comorbidities, %				0.149				< 0.001
0	56.59	64.57	59.28		40.34	57.74	54.09	
1	31.78	28.90	31.96		35.29	33.57	32.30	
2+	11.63	6.53	8.76		24.37	8.69	13.62	

Note. a. Comparison between female lung cancer, breast cancer and female colorectal cancer.

b. Comparison between male lung cancer, prostate cancer, and male colorectal cancer.

	Female				Male			
Self-reported walking pace, %				< 0.001				< 0.001
Slow	15.50	478.	8.76		11.76	3.35	6.61	
Steady or average	54.26	51.86	47.94		53.78	48.69	52.14	
Brisk	30.23	43.36	43.30		34.45	47.71	41.25	
Grip strength in kg, mean (SD)	24.32 (6.64)	25.08 (6.29)	24.62 (5.81)	0.339	38.93 (8.32)	41.09 (8.33)	39.87 (8.08)	< 0.01
Anxiety and depression, mean (SD)	5.48 (2.12)	5.26 (1.94)	5.24 (1.72)	0.456	5.03 (1.58)	5.02 (1.55)	4.99 (1.64)	0.930
Accelerometer measured PA								
Total acceleration, mean (SD)	25.31 (7.79)	27.50 (7.32)	26.57 (7.11)	< 0.01	22.87 (6.83)	26.91 (8.74)	24.82 (7.47)	< 0.001
MVPA (min/day), mean (SD)	91.05 (44.16)	106.74 (43.37)	101.98(45.02)	< 0.001	77.95 (36.04)	101.49 (45.72)	91.41 (44.11)	< 0.001
Moderate PA (min/day), mean (SD)	88.72 (41.90)	103.53 (40.99)	99.65 (43.50)	< 0.001	75.78 (34.49)	97.40 (43.06)	88.27 (42.11)	< 0.001
Vigorous PA (min/day), mean (SD)	2.33 (4.37)	3.20 (4.86)	2.33 (3.20)	< 0.05	2.18 (4.04)	4.09 (5.89)	3.14 (4.28)	< 0.001
Note. a. Comparison between female lung cancer, breast cancer and female colorectal cancer.								
b. Comparison between male lung cancer, prostate cancer, and male colorectal cancer.								

When stratifying by gender, the total acceleration was 25.31 mg/day and 22.87 mg/day in female and male lung cancer groups respectively; this was lower than other types of cancer ($P < 0.01$). The time spent in MVPA per day was 91 and 78 min/day in female and male lung cancer groups respectively; this was lower than other types of cancer ($P < 0.001$) (see Table 1).

3.2 Comparison of pre-diagnosis PA

In the unadjusted linear regression models of females, participants in the breast and colorectal cancer group spent 15.68 (95% CI: 7.58, 23.78, $P < 0.001$) and 10.93 (95% CI: 1.18, 20.67, $P < 0.05$) more minutes in MVPA respectively, compared with participants in the lung cancer group. The difference disappeared with adjustment for socio-demographic characteristics (see Table 2 for details).

Table 2
Comparison of time spent in moderate to vigorous physical activity between different type of cancer (min/day) (stratified by gender)

	Female (n = 1,181)		Male (n = 1,481)	
	Unadjusted coefficient b (95% CI)	Adjusted coefficient [a] b (95% CI)	Unadjusted coefficient b (95% CI)	Adjusted coefficient [a] b (95% CI)
Type of cancer				
Lung cancer	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)
Breast cancer	15.68 (7.58, 23.78) ***	5.62 (-2.26, 13.50)	–	–
Colorectal cancer	10.93 (1.18, 20.67) *	6.37 (-2.90, 15.64)	13.46 (3.72, 23.19) **	6.33 (-2.97, 15.64)
Prostate cancer	–	–	23.54 (15.07, 32.01) ***	15.32 (7.11, 23.53) ***
Age at accelerometer study		-1.61 (-1.94, -1.27) ***		-2.41 (-2.78, -2.04)
White race (reference: non-white)		-0.49 (-15.38, 14.39)		-7.72 (-23.36, 7.91)
Townsend Index of deprivation		-0.31 (-1.15, 0.53)		-0.32 (-1.14, 0.49)
BMI				
Underweight		8.65 (-15.84, 33.15)		64.43 (-17.77, 146.613)
Normal		0.00 (reference)		0.00 (reference)
Overweight		-9.44 (-14.75, -4.14) ***		-11.35 (-16.49, -6.20) ***
Obese		-21.74 (-28.27, -15.21) ***		-24.20 (-30.54, -17.85) ***
Smoking status				
Never		0.00 (reference)		0.00 (reference)
Previous		1.08 (-3.97, 6.13)		5.68 (1.04, 10.32) *
Current		-14.26 (-23.61, -4.90) **		-11.73 (-20.18, -3.28) **
Alcohol drinking frequency				
≤1–3 times/month		0.00 (reference)		0.00 (reference)
1–4 times/week		9.43 (3.94, 14.92) **		6.60 (0.55, 12.65) *
Daily or almost daily		12.66 (5.94, 19.38) ***		7.63 (1.11, 14.16) *
Note. a. adjusted for age, race, Townsend Index of deprivation, BMI, smoking status and alcohol drinking frequency.				
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.				

In the unadjusted linear regression models for males, participants in the colorectal and prostate cancer group spent 13.46 (95% CI: 3.72, 23.19, $P < 0.01$) and 23.54 (95% CI: 15.07, 32.01, $P < 0.001$) more minutes in MVPA respectively, compared with participants in the lung cancer group. With adjustment for socio-demographic characteristics, the difference between colorectal and lung cancer was not statistically significant, but participants in prostate cancer group still showed 15.32 more minutes in MVPA per day compared with lung cancer (95% CI: 7.11, 23.53, $P < 0.001$) (see Table 2 for details).

3.3 Comparison of correlates of pre-diagnosis PA

In the unadjusted linear regression models, higher pre-diagnosis PA was associated with younger age, lower BMI, better self-rated health, fewer comorbidities, and faster self-rated walking pace in all the four types of cancer ($P < 0.01$). In the lung cancer group, higher pre-diagnosis PA was also associated with never smoking, more frequent alcohol consumption and lower anxiety and depression ($P < 0.01$) (See Table 3).

Table 3
Comparison of correlates of time spent in MVPA (min/day) between lung, breast, colorectal and prostate cancer

	Lung cancer (n = 248)		Breast cancer (n = 858; only females)		Colorectal cancer (n = 451)		Prostate cancer (n = 1,105; only males)	
	Unadjusted coefficient	Adjusted coefficient	Unadjusted coefficient	Adjusted coefficient	Unadjusted coefficient	Adjusted coefficient	Unadjusted coefficient	Adjusted coefficient
Male (reference: female)	-13.10 (-23.23, -2.97) *	1.36 (-12.66,15.39)	–	–	-10.57 (-18.89, -2.25) *	-3.02 (-14.92, 8.89)	–	–
Age at accelerometer study	-2.29 (-3.10, -1.48) ***	-2.35 (-3.22, -1.48) ***	-1.57 (-1.94, -1.19) ***	-1.50 (-1.90, -1.11) ***	-2.16 (-2.76, -1.56) ***	-2.02 (-2.66, -1.38) ***	-2.31 (-2.76, -1.85) ***	-2.37 (-2.84, -1.90) ***
White (reference: non-white)	-8.80 (-42.16, 24.55)	-3.04 (-32.88,26.80)	-5.86 (-24.25, 12.53)	-3.31 (-20.64, 14.01)	-10.49 (-40.13, 19.14)	-18.66 (-47.62, 10.30)	-9.91 (-28.81, 8.99)	-8.08 (-25.98, 9.82)
Townsend Index of Deprivation	-2.14 (-3.76, -0.51) *	-1.23 (-2.80, 0.36)	0.28 (-0.79, 1.34)	0.65 (-0.36, 1.65)	-0.72 (-2.15, 0.72)	-0.52 (-1.87, 0.83)	0.27 (-0.77, 1.31)	0.18 (-0.81, 1.17)
BMI								
Underweight	-54.23 (-134.20, 25.73)	-47.59 (-120.05, 24.87)	27.86 (-1.76, 57.48)	19.05 (-9.05, 47.15)	-11.89 (-73.42, 49.63)	-25.84 (-85.79, 34.12)	48.89 (-39.50, 137.29)	62.0 (-21.24, 145.29)
Normal	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)
Overweight	-8.96 (-21.21, 3.30)	-3.86 (-15.02, 7.30)	-14.31 (-20.60, -8.02) ***	-8.48 (-14.60, -2.35) **	-11.19 (-20.67, -1.70) *	-5.85 (-15.07, 3.37)	-11.52 (-17.78, -5.27) ***	-7.95 (-13.97, -1.92) *
Obese	-19.79 (-32.76, -6.82) **	-8.36 (-21.19, 4.47)	-25.54 (-33.51, -17.56) ***	-14.99 (-22.94, -7.04) ***	-25.21 (-36.41, -14.01) ***	-17.04 (-28.26, -5.82) **	-24.85 (-32.77, -16.94) ***	-17.97 (-25.92, -10.03) ***
Smoking status								
Never	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)
Previous	-18.09 (-30.57, -5.62) **	-7.06 (-18.83, 4.70)	1.09 (-5.07, 7.26)	3.71 (-2.08, 9.50)	3.88 (-4.70, 12.46)	10.80 (2.49, 19.12) *	-1.56 (-7.13, 4.00)	7.23 (1.87, 12.59) **
Current	-34.96 (-49.55, -20.37) ***	-26.43 (-40.30, -12.56) ***	-8.62 (-20.82, 3.58)	-8.88 (-20.24, 2.47)	-8.49 (-25.43, 8.44)	-3.02 (-18.96, 12.91)	-7.36 (-19.15, 4.43)	-5.90 (-17.06, 5.25)
Alcohol drinking frequency								
≤1–3 times/month	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)
1–4 times/week	16.51 (4.70, 28.33) **	1.90 (-9.12, 12.92)	11.43 (4.70, 18.17) **	7.71 (1.37, 14.06) *	10.11 (-0.39, 20.61)	5.14 (-5.06, 15.34)	5.79 (-1.87, 13.45)	4.25 (-2.94, 11.45)
Daily or almost daily	17.45 (4.23, 30.67) *	8.97 (-3.16, 21.11)	11.78 (3.58, 19.99) **	9.55 (1.71, 17.39) *	7.25 (-4.07, 18.58)	6.07 (-5.19, 17.34)	4.55 (-3.76, 12.83)	2.44 (-5.45, 10.32)

Note. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

	Lung cancer (n = 248)		Breast cancer (n = 858; only females)		Colorectal cancer (n = 451)		Prostate cancer (n = 1,105; only males)	
Overall health rating								
Excellent	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)
Good	-3.87 (-20.54, 12.81)	0.93 (-14.05, 15.91)	-5.21 (-12.58, 2.15)	-0.55 (-7.71, 6.61)	-15.96 (-26.83, -5.08) **	-10.21 (-20.75, 0.32)	-8.23 (-14.89, -1.57) *	-4.22 (-10.72, 2.28)
Fair	-21.98 (-40.20, -3.75) *	-1.36 (-19.16, 16.43)	-18.80 (-29.06, 8.54) ***	-6.91 (-17.48, 3.65)	-23.17 (-36.98, -9.37) **	-11.27 (-25.66, 3.12)	-23.22 (-31.88, -14.55) ***	-12.53 (-21.70, -3.35) **
Poor	-36.90 (-61.28, -12.52) **	-15.35 (-43.42, 12.71)	-33.90 (-53.36, -14.43) **	-20.77 (-41.01, -0.53) *	-42.00 (-69.84, -14.17) **	-24.24 (-53.20, 4.71)	-49.46 (-73.73, -25.18) ***	-41.36 (-66.04, -16.67) **
No. of comorbidities	-12.87 (-18.11, -7.64) ***	-3.10 (-9.02, 2.81)	-8.36 (-12.84, -3.88) ***	-2.40 (-6.80, 2.02)	-9.69 (-15.12, -4.27) ***	-2.39 (-7.82, 3.05)	-11.34 (-15.00, -7.68) ***	-4.22 (-8.02, -0.42) *
Self-reported walking pace								
Slow	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)	0.00 (reference)
Steady or average	25.64 (1-.99, 40.29) **	11.36 (-3.54, 26.26)	26.85 (13.41, 40.28) ***	16.36 (2.53, 30.18) *	22.72 (7.14, 38.31) **	20.41 (3.93, 36.89) *	30.15 (15.16, 45.13) ***	14.57 (-0.09, 29.22)
Brisk	43.24 (27.62, 58.86) ***	23.06 (6.52, 39.60) ***	44.12 (30.57, 57.67) ***	29.08 (14.84, 43.33) ***	41.78 (26.00, 57.56) ***	31.01 (13.82, 48.20) ***	41.84 (26.85, 56.83) ***	21.34 (6.37, 36.31) **
Grip strength (kg)	-0.08 (-0.57, 0.41)	-0.60 (-1.28, 0.08)	0.50 (0.04, 0.96) *	-3.36 (-0.82, 0.10)	-0.05 (-0.45, 0.34)	-0.27 (-0.85, 0.30)	0.18 (-0.15, 0.50)	-0.27 (-0.69, -0.05) *
Anxiety and depression	-4.08 (-6.75, -1.40) **	-1.54 (-4.38, 1.30)	-1.30 (-2.80, 0.20)	-0.67 (-2.18, 0.85)	0.29 (-2.26, 2.84)	0.09 (-2.43, 2.60)	-0.28 (-1.93, 1.36)	0.56 (-1.05, 2.17)
Adjusted R^2	–	28.56%	–	16.28%	–	18.44%	–	14.98%
VIF	–	1.12–3.20	–	1.03–7.05	–	1.09–5.15	–	1.01–9.03

Note. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

In the adjusted linear regression models, we compared the relative strength of the correlates on PA in each type of cancer. Younger age and faster walking pace had a strong association with PA in all the four types of cancer ($P < 0.01$). In addition, smoking status had a strong negative association with PA in lung cancer group, while obesity had a strong negative association with PA in breast, colorectal and prostate cancer ($P < 0.01$) (see Table 3 and Supplemental Table 2).

3.4 Survival analysis

A total of 2,662 cancer cases diagnosed between 2013 and 2020 were followed up to 2021 (up to 7.4 years). There were 426 deaths among 2,661 participants during the follow-up period (one participant died on the same day of cancer diagnosis). Cox regression analyses showed that higher levels of pre-diagnosis MVPA (≥ 1.5 hours/day) were associated with a significantly lower all-cause mortality risk after cancer diagnosis ($HR = 0.57–0.68$, $P < 0.01$) (see Table 4). However, no significant difference for all-cause mortality was found between “MVPA = 1-1.5 hours/day” and “MVPA less than 1 hour/day” ($P > 0.05$). Compared to lung cancer, patients with other types of cancer had a significantly lower all-cause mortality risk ($HR = 0.08–0.31$, $P < 0.001$) (see Table 4). There was no significant

interaction between cancer types and MVPA on all-cause mortality, see Supplemental Table 3. The association between PA and mortality was not significantly different between different cancer types.

Table 4
The relationship between pre-diagnosis MVPA (hours/day) and all-cause death after cancer diagnosis (n = 2,661)

	Unadjusted Hazard Ratio (n = 2,661, No. of events = 426)	Adjusted Hazard Ratio[a] (n = 2,661, No. of events = 426)
Time in MVPA (hours/day)		
<1 hour (reference)	1.0 (Reference)	1.0 (Reference)
1-1.5 hours	0.63 (0.50, 0.81) ***	0.90 (0.69, 1.16)
1.5-2 hours	0.49 (0.38, 0.64) ***	0.68 (0.52, 0.91) **
≥2 hours	0.32 (0.24, 0.43) ***	0.57 (0.42, 0.78) ***
Cancer type		
Lung cancer (reference)		1.0 (Reference)
Female breast cancer		0.08 (0.05, 0.11) ***
Colorectal cancer		0.31 (0.24, 0.41) ***
Prostate cancer		0.08 (0.06, 0.10) ***
Male (reference: female)		1.25 (0.97, 1.62)
Age at cancer diagnosis		
<65 years		1.0 (Reference)
65–70 years		0.94 (0.68, 1.28)
70–75 years		1.25 (0.94, 1.66)
≥75 years		1.49 (1.08, 2.04) *
White race (reference: non-white)		1.58 (0.68, 3.65)
Townsend Index of deprivation		1.00 (0.96, 1.03)
BMI		
Underweight		3.24 (0.98, 10.66)
Normal		1.0 (Reference)
Overweight		1.04 (0.82, 1.32)
Obese		1.04 (0.79, 1.39)
Smoking status		
Never		1.0 (Reference)
Previous		1.18 (0.95, 1.47)
Current		1.47 (1.07, 2.02) *
Alcohol drinking frequency		
≤1–3 times/month		1.0 (Reference)
1–4 times/week		1.40 (1.08, 1.82) *
Daily or almost daily		1.25 (0.94, 1.67)

Note. a. adjusted for gender, age, race, Townsend Index of deprivation, BMI, smoking status, alcohol drinking frequency and comorbidities. *P < 0.05, **P < 0.01, ***P < 0.001

	Unadjusted Hazard Ratio (n = 2,661, No. of events = 426)	Adjusted Hazard Ratio[a] (n = 2,661, No. of events = 426)
Diabetes		1.42 (0.97, 2.08)
Heart attack		0.77 (0.45, 1.32)
Angina		0.72 (0.42, 1.24)
Stroke		1.54 (0.87, 2.74)
Hypertension		0.94 (0.75, 1.17)
COPD		1.37 (0.85, 2.20)
Asthma		0.86 (0.63, 1.18)
Note. a. adjusted for gender, age, race, Townsend Index of deprivation, BMI, smoking status, alcohol drinking frequency and comorbidities. *P < 0.05, **P < 0.01, ***P < 0.001		

4. Discussion

To our knowledge, this study is the first to compare pre-diagnosis PA and its correlates between patients with lung cancer and other types of cancer (e.g., breast, colorectal and prostate cancer) using a national cohort dataset with objective measures. We found that lung cancer patients were the most physically inactive population before diagnosis compared to breast and colorectal cancer, but this difference could be explained by socio-demographic characteristics. We identified correlates of pre-diagnosis PA among patients with each type of cancer and detected differences between lung cancer and other types of cancer (breast, colorectal and prostate cancer). Specifically, smoking status was negatively associated with pre-diagnosis PA in lung cancer only, while obesity was negatively associated with pre-diagnosis PA in the breast, colorectal and prostate cancer groups. Furthermore, we found that higher MVPA before diagnosis (≥ 1.5 hours/day) was associated with a lower all-cause mortality risk after lung, breast, colorectal and prostate cancer diagnosis.

4.1 Pre-diagnosis MVPA

Our study found that the lower pre-diagnosis MVPA in lung cancer patients could be explained by socio-demographics. This was also observed by Sweegers et al. (2019) for post-diagnosis MVPA. [37]; Sweegers et al. compared post-diagnosis MVPA between lung cancer survivors and breast cancer survivors and found no significant difference after controlling for age, sex, and smoking status.

The pre-diagnosis MVPA in our study appears high in comparison to previous estimates [8, 37] and the recommended MVPA guidelines (150 min/week) [4]. However, it is difficult to compare across studies given the use of different devices and cut points in cancer research [38]. A review of 46 articles summarized the accelerometer data in cancer survivors and reported that time spent in MVPA ranged from 3.7 min/day to 150 min/day [38]. A few studies with UK Biobank data and the same cut-points found that cancer survivors and patients with chronic diseases spent similar amount of time in MVPA, compared to this current study [31, 39].

4.2 Correlates of PA

We found two strong correlates of pre-diagnosis MVPA in all four types of cancer: age and walking speed. Age is a well-established predictor of PA. Prior studies with accelerometers reported a negative association between age and PA in general cancer survivors [8, 37] and patients with breast [17, 27], colorectal [26], and lung cancer [40]. Walking speed/pace is considered to be a “vital sign” and indicative of functional status and health outcomes [41, 42], and it is a recognized predictor of daily PA in older adults [43]. This study extends the finding from prior studies of post-diagnosis PA or PA in older adults and identified walking speed as a predictor of pre-diagnosis MVPA.

The differences in PA correlates between cancer types was observed by prior studies with self-reported PA measures[6, 15]. Our study identified cancer specific PA correlates: smoking status and obesity. Smoking was a strong correlate of pre-diagnosis MVPA in lung cancer patients only. This finding is consistent with previous studies in post-diagnosis PA of lung cancer patients [40]. However, a few studies of a mixed cancer population reported inconsistent findings regarding whether smoking status was associated with PA [5, 37]. The inconsistent findings could be potentially explained by the proportion of lung cancer patients in the mixed cancer population, given that the association between smoking status and PA was predominantly present in lung cancer [37]. Obesity was a strong correlate of

pre-diagnosis MVPA in the breast, colorectal and prostate cancer patients. Similar results were also found in PA of general cancer survivors [5, 37], colorectal cancer survivors [26], and breast cancer survivors [27]. However, obesity was not a strong correlate of MVPA in lung cancer patients [40].

Our study supports the finding of prior studies that focused on only one of these cancer types, and it also helps explain the inconsistent findings of prior studies with mixed cancer populations. Future studies may consider the similarity within and differences between cancer types when merging a mixed cancer population. The identified differences in PA and its correlates between cancer types suggest that cancer-specific approaches are needed to identify patients at high risk of physical inactivity. For example, PA interventions in lung cancer could target smokers, who are at higher risk for low PA than non-smokers. Given the correlation between smoking and PA, behavioral change interventions might be more effective to combine smoking cessation and PA promotion for smokers.

4.3 Pre-diagnosis PA and all-cause mortality

Our study, with a national cohort of accelerometer data, confirms the findings from previous studies of self-reported PA measures [2] and supports the benefits of pre-diagnosis MVPA on improved survival outcomes. Recent meta-analyses found that higher pre-diagnosis PA was protective against cancer-specific mortality following breast, colorectal, and lung cancer and against all-cause mortality among breast, colorectal and prostate cancer [2], but the majority of included studies used self-reported PA measures and few studies examined the dose-response effects of MVPA on mortality. Our study filled this research gap and found that engaging in less than 1.5 h/day of MPVA may not provide significant benefits for survival. However, this finding should be interpreted with caution considering the MVPA was measured with a wrist-worn accelerometer (less accurate than hip-worn accelerometer when using cut points [44]). In addition, our study also suggests that the effect of MVPA on survival is not modified by different cancer types. Patients with each type of cancer may receive the same survival benefits from the same PA levels. In addition to mortality, a previous study also found that pre-diagnosis PA is a strong influencing factor of early recurrences of slow-growing cancer [45] and it is also an important predictor of post-diagnosis PA [15]. The above evidence highlights the need for PA promotion among people with higher cancer risks.

4.4 Limitations

This study has major strength, but it also has several limitations. First, the accelerometer data were not collected immediately prior to the cancer diagnosis, there is a time interval (4 days-6.5 years) between PA assessment and cancer diagnosis. Thus, this may not be representative of participants' overall pre-diagnosis PA levels. We assume that PA remains roughly the same before cancer diagnosis while controlling for age. Second, we did not have information on cancer stage and cancer treatments, which are confounding variables in PA and survival. Third, accelerometer study participants represent a subset of the UK Biobank participants who were willing and able to join a study on objective measurement of PA, but may not be representative of the broader UK population [31]. Fourth, time spent in MVPA is high in this study, but we could not determine if people meet PA guidelines based on the MVPA data considering the nature of wrist-worn accelerometer.

5. Conclusion

Understanding pre-diagnosis PA and its correlates is helpful in promoting PA and ultimately improving health outcomes in cancer patients. This study is the first to compare objectively measured pre-diagnosis MVPA and its correlates between patients with lung cancer and other common cancers, and the first to examine the dose-response relationship between MVPA and all-cause mortality, using a national cohort. Lung cancer patients are the most physically inactive population before diagnosis compared to breast and colorectal cancer, but this difference could be explained by socio-demographic characteristics. Age and walking speed are strong PA correlates in all four types of cancer, while smoking status is a unique correlate in lung cancer. This study confirms the finding of prior studies that focused on only one of these cancer types and suggests cancer-specific approaches in PA research and practice, especially for lung cancer. Higher pre-diagnosis MVPA (> 1.5h) is associated with a lower all-cause mortality risk, which highlights the importance of high PA for individuals with high cancer risk.

Declarations

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Conflicts of interest/Competing interests: The authors disclose no conflict of interest.

Availability of data and material: Data from UK Biobank are available to researchers on application. This research has been conducted using the UK Biobank resource under application number 73792.

Authors' contributions: WZ and JL had the idea for the article, WZ and PV contributed to the data analysis, WZ drafted the manuscript, WZ, JL, ES, WC, PV and RR revised the manuscript.

Ethics approval: This study used data from the UK Biobank. UK Biobank was approved by the North West Multicenter Research Ethics Committee. This study was reviewed and deemed not regulated by the University of Michigan Institutional Review Board.

Consent to participate: Not applicable

Consent for publication: Not applicable

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Figures

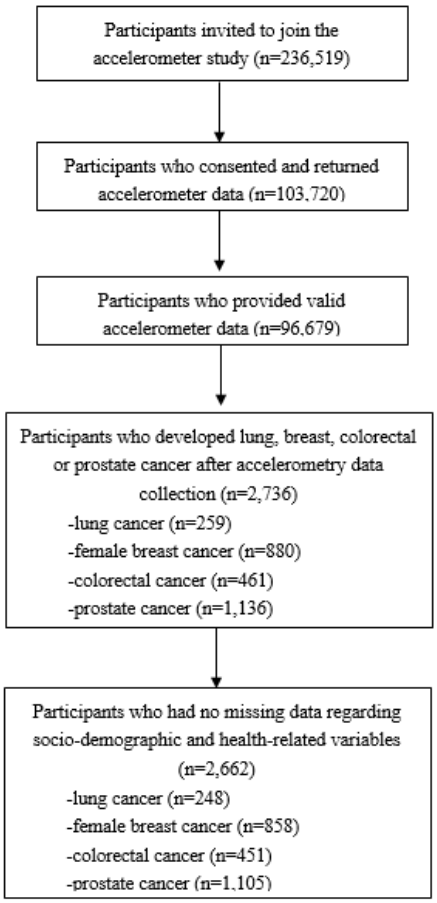

Figure 1

Flowchart of study sample

Supplementary Files

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