Cancer Causes & Control (2019) 30:617–625
https://doi.org/10.1007/s10552-019-01138-6

ORIGINAL PAPER

Lifetime recreational physical activity and the risk of prostate cancer

Elizabeth Sorial[1] · Si Si[1] · Lin Fritschi[1] · Ellie Darcey[1,2] · Justine E. Leavy[1] · Jennifer Girschik[3,4] · Gina L. Ambrosini[4] · Terry Boyle[1,5]

Received: 10 September 2018 / Accepted: 6 February 2019 / Published online: 8 April 2019
© Springer Nature Switzerland AG 2019

Abstract

Purpose Research on the association between physical activity and the risk of prostate cancer is inconsistent. The aim of this study was to investigate whether the timing, intensity, and type of recreational physical activity influence prostate cancer risk.

Methods A population-based case–control study was conducted in Western Australia in 2001–2002. Data were collected on lifetime recreational physical activity from a self-reported questionnaire. The estimated effects of recreational physical activity on prostate cancer risk were analyzed using logistic regression, adjusting for demographic and lifestyle factors. This analysis included 569 incident cases and 443 controls.

Results There was a significant, inverse dose–response relationship between vigorous-intensity recreational physical activity between the ages 19 and 34 years and the risk of prostate cancer ($p_{\text{Trend}} = 0.013$). Participants in the most active quartile of vigorous-intensity physical activity in this age period had a 33% lower risk of prostate cancer than participants in the least active quartile (Adjusted Odds Ratio = 0.67, 95% confidence interval = 0.45–1.01). Moderate-intensity recreational physical activity was not associated with the risk of prostate cancer. Recreational physical activity performed over the lifetime showed no association with prostate cancer risk. Weight training performed from early adulthood onwards showed a non-significant but consistent inverse association with prostate cancer risk. There was no strong evidence that physical activity was differentially associated with the risks of low-grade and medium-to-high grade prostate cancers.

Conclusions A high level of vigorous recreational physical activity in early adulthood may be required to reduce the risk of prostate cancer.

Keywords Prostate cancer · Physical activity · Epidemiology · Resistance training

Background

Prostate cancer is the most frequently diagnosed cancer among males worldwide; however, the risk factors for prostate cancer are not clearly understood [1, 2]. Known non-modifiable risk factors include age, height, family history, and ethnicity [1, 2]. Less is known about modifiable risk factors for prostate cancer, although there is some evidence that obesity, dietary factors, and physical activity may be associated with prostate cancer risk [1].

Physical activity is an important primary prevention strategy for several chronic diseases, such as type 2 diabetes, cardiovascular disease, and cancers including colon and breast cancer [3]. A considerable number of studies have investigated the association between physical activity and the risk of prostate cancer; however, overall findings are inconsistent [4–6]. A 2011 meta-analysis found a modest inverse association between recreational physical activity

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10552-019-01138-6) contains supplementary material, which is available to authorized users.

✉ Terry Boyle
terry.boyle@unisa.edu.au

1 School of Public Health, Curtin University, Perth, Australia

2 Centre for Genetic Origins of Health and Disease, School of Biomedical Science, Curtin University and The University of Western Australia, Perth, WA, Australia

3 Epidemiology Branch, Department of Health Western Australia, Perth, Australia

4 School of Population and Global Health, The University of Western Australia, Perth, Australia

5 Australian Centre for Precision Health, School of Health Sciences, University of South Australia Cancer Research Institute, GPO Box 2471, Adelaide, SA 5001, Australia

and the risk of prostate cancer based on 19 cohort studies (summary relative risk = 0.95, 95% CI 0.89–1.00) and 24 case–control studies (summary odds ratio = 0.95, 95% CI 0.90–1.00) [4], while a more recent meta-analysis found insufficient statistical evidence for an association between overall physical activity and prostate cancer risk [7]. One reason for the inconsistent results to date may be that few studies have taken into account the intensity, timing, and type of physical activity, all of which have been shown to influence the association between physical activity and cancer risk [8, 9]. Another reason for the inconsistent results may be that many studies have not taken the heterogenous nature of prostate cancer into account [7]. Prostate cancers range from indolent to highly aggressive and it is possible that physical activity may be differentially associated with different subtypes of prostate cancer (as defined by grade or stage).

Examining timing, intensity, and type of physical activity will lead to a better understanding of the role that physical activity may play in prostate cancer risk [10]. Previous research indicates that physical activity performed in specific age periods may reduce prostate cancer risk [10–14]. These studies have tended to find that increasing physical activity levels during the age periods 20–45 years and 46–65 years is associated with a significant reduction in the risk of prostate cancer, but physical activity before the age of 20 and after the age of 65 is not [4]. However, there is insufficient evidence as to whether there are any critical age periods in which physical activity may confer a greater benefit in prostate cancer risk reduction. Similarly, although some studies have found a larger risk reduction associated with vigorous-intensity physical activity than with moderate-intensity physical activity, the evidence is not clear [4, 15]. Finally, all previous studies on physical activity and prostate cancer have focussed on aerobic activity, and it is not known if different types of physical activity such as resistance training (e.g., weight training) are associated with prostate cancer risk. Some studies have found that resistance training is associated with lower cancer mortality [16, 17] and a lower risk of some cancers [18], so it is important to investigate the association between resistance training and prostate cancer risk.

The aims of this study were to (1) investigate the overall association between recreational physical activity and prostate cancer risk; (2) investigate the association between recreational physical activity in specific age periods and prostate cancer risk; (3) investigate whether intensity influences the association between physical activity and risk of prostate cancer; (4) investigate whether resistance training is associated with prostate cancer risk; and (5) investigate whether physical activity was differentially associated with the risks of low-grade and medium-to-high grade prostate cancers.

Methods

Study design

The Western Australian Prostate Health Study was a population-based case–control study conducted over a 2-year period, commencing in January 2001 [19]. The WA Prostate Health Study was approved by the human research ethics committee (HREC) of The University of Western Australia and the Confidentiality of Health Information Committee, Department of Health, Western Australia. The current analysis was approved by the Curtin University HREC. Participants gave written informed consent.

Participants

Cases in the Prostate Health Study were identified from the Western Australia cancer registry. Inclusion criteria included cases with a histopathologically confirmed incident prostate cancer in Western Australia between 1 January 2001 and 30 August 2002. Cases were aged between 40 and 75 years at the time of diagnosis. Exclusion criteria included patients with previous diagnosis of prostate cancer or patients who lacked English comprehension. A total of 1,066 cases were identified as potentially eligible to participate in the study, of whom 606 cases (57% response rate) participated.

Controls in the Prostate Health Study were men aged 40–75 years who had never been diagnosed with prostate cancer and were randomly selected from the Western Australian electoral roll, between 1 August 2001 and 1 October 2002. Voting is compulsory in Australia and, as such, the electoral roll is considered a virtually complete sampling frame. The controls were frequency age-matched to the predicted age distribution of the patients with prostate cancer in 5-year age groups. A total of 1,272 controls were identified as potentially eligible to participate in the study. Based on the inclusion and exclusion criteria of the cases, 471 (37%) controls participated.

Data collection

The cases and controls completed a self-administered questionnaire about demographic details, family history, anthropometric data, lifetime occupational and residential history, military history, lifetime physical activity, alcohol consumption, smoking history, and medical history. A dietary questionnaire, which asked questions about the participant's dietary habits and alcohol consumption 10 years prior, was also completed by participants [20].

The physical activity questionnaire was adapted from the Historical Physical Activity Questionnaire, which has been shown to have high test–retest reliability and moderate to good convergent validity with other lifetime physical activity questionnaires [21–23]. The historical physical activity questionnaire was designed to assess the duration, frequency, and intensity of lifetime recreational activities [21]. This questionnaire was modified to make the recreational physical activities more applicable to Australian men (e.g., winter activities such as snow-skiing were removed). The questionnaire asked participants to recall and record the hours per week, the number of months per year, and the number of years for the activities listed (and any other activities) in the questionnaire in four specific age periods: 12–18 years, 19–34 years, 35–49 years, and 50 years and older.

Data processing

Based on the data from the participants, the average number of hours/week for each recreational activity in each age period and over the lifetime (i.e., 12 years old to current age at study participation) was estimated. The average MET-hours/week for each activity in each age period was estimated by multiplying the average number of hours/week by the assigned MET value from the Compendium of Physical Activity [24]. The totals were summed to create a MET-hour/week total for each age period. To estimate intensity, activities with a MET value between 3 and 5.9 were classified as moderate and activities with a MET value of 6 or greater were classified as vigorous, and the MET-hour/week total for each was estimated [24]. Average MET-hours per week in resistance training was calculated based on the time participants reported performing "Weight Training (Gym Work)."

The average MET-hours/week over the lifetime for each of total, moderate-, and vigorous-intensity physical activity and resistance training was estimated, and we then classified the participants into quartiles, based on the distribution among controls. To investigate the associations between physical activity performed in specific age periods and prostate cancer risk, participants were classified into tertiles or quartiles of total, moderate, and vigorous physical activity and resistance training within each specific age period, based on the distribution of activity in controls.

Statistical analyses

Descriptive statistics were used to summarize the characteristics of the cases and controls. To assess the association between recreational physical activity and prostate cancer risk, logistic regression was performed. In the first analysis, logistic regression was used to investigate the association between total physical activity and prostate cancer risk within each age period and over the lifetime. In the second analysis, logistic regression was used to investigate the associations between moderate and vigorous physical activity intensities and resistance training and risk of prostate cancer in each age period and over the lifetime. We also used multinomial logistic regression models to investigate the associations between physical activity and the risks of medium-to-high grade prostate cancer (defined by a Gleason score of seven or greater) and low-grade prostate cancer (Gleason score of six or less).

Age was included as a covariate in all analyses as the controls were age-frequency matched with the cases. A directed acyclic graph was used to inform the choice of additional covariates [25], which resulted in the following variables being included in the model as confounders: body mass index 10 years prior to the study, smoking status, alcohol consumption 10 years prior to the study, socioeconomic status, family history of prostate cancer, energy intake 10 year prior to the study, and lifetime occupational physical activity. Socioeconomic status was assessed at the area level (postcode) using the index of relative socioeconomic disadvantage from the Australian Bureau of Statistics Socio-Economic Indexes for Areas [26]. Moderate- and vigorous-intensity physical activity and resistance training were adjusted for each other. Total physical activity in all previous age periods was adjusted for in analyses investigating the association between physical activity in a specific age period and prostate cancer risk. A total of 37 cases and 28 controls were excluded due to missing data on one or more covariate, leaving 569 cases and 443 controls in this analysis.

In a sensitivity analysis, we additionally adjusted for time since last prostate cancer test (blood/PSA test or digital rectal examination); however, including this variable did not result in any meaningful change to the observed results and so was not included in the final analysis. We also performed a sensitivity analysis to investigate the effect of potential non-differential exposure misclassification on the observed odds ratios for physical activity (total, moderate-intensity, and vigorous-intensity) between the ages 19 and 34 years. We first created a contingency table based on the adjusted odds ratios, then in turn reclassified 10%, 20%, and 50% of the cases and controls in each of the exposure categories to the category immediately below it (i.e., one category closer to the reference category). We then calculated the ORs from the new contingency tables to estimate the potential effect of non-differential misclassification. A significance level of $p=0.05$ was used in all analyses. All analyses were performed using Stata 14.0 (StataCorp, College Station TX, USA).

Results

Participant characteristics

Table 1 displays the characteristics of the cases and controls in the Prostate Health Study. Cases were younger than the controls and more likely to have a family history of prostate cancer. The distribution of alcohol consumption, smoking, socioeconomic status, energy intake, and occupational physical activity was similar between cases and controls. Of the 569 cases, 235 had low-grade prostate cancer and 315 had a medium-to-high grade prostate cancer. Gleason score was not available for 19 cases.

Recreational physical activity and prostate cancer risk

Higher levels of total recreational physical activity and moderate-intensity recreational physical activity in the teenage years (12–18 years) were associated with a small increased risk of prostate cancer, although this was not statistically significant. Vigorous-intensity physical activity was not associated with risk in this age period (Table 2).

In contrast, higher levels of total recreational physical activity in early adulthood (19–34 years) were associated with a lower risk of prostate cancer ($p_{\text{Trend}} = 0.044$). Moderate-intensity physical activity alone was not associated with prostate cancer risk; however, vigorous-intensity physical activity was inversely associated with the risk of prostate cancer ($p_{\text{Trend}} = 0.013$). Participants in the most active quartile of vigorous-intensity physical activity had a 33% lower risk of prostate cancer than participants in the least active quartile (Adjusted Odds Ratio (AOR) = 0.67, 95% Confidence Interval (CI) 0.45–1.01).

There were no clear associations between total, moderate-, or vigorous-intensity recreational physical activity in the age periods 35–49 years and 50+ years and prostate cancer risk. Average recreational physical activity level over the lifetime was also not associated with the risk of prostate cancer (Table 2).

No significant heterogeneity was found between the associations for any of the physical activity variables and the risks of medium-to-high grade and low-grade prostate cancers (Online Resource 1).

Sensitivity analyses suggested any potential non-differential exposure misclassification had very minimal influence on the odds ratios observed for total, moderate-intensity, and vigorous-intensity physical activity (data not shown).

Weight training and prostate cancer risk

The prevalence of weight training was low in each age period (≤ 10%) and over the lifetime (≤ 20%). Participants with the highest levels of weight training over the lifetime and during the age periods of 19–34 years, 35–49 years, and 50+ years had a lower risk of prostate cancer than participants who reported performing no weight training; however, none of these associations were statistically significant (Table 3). No significant heterogeneity was found between the associations

Table 1 Characteristics of the participants in the Western Australian Prostate Health Study

Characteristic	Controls (*n* = 443)		Cases (*n* = 569)	
	n	%	*n*	%
Age group (years)				
40–54	27	6.1	67	11.8
55–59	56	12.6	104	18.3
60–64	101	22.8	112	19.7
65–69	127	28.7	147	25.8
70+	132	29.8	139	24.4
Alcohol consumption 10 years ago (g/day)				
0–3.2	110	24.8	117	20.6
3.3–16.9	109	24.6	164	28.8
17–36.3	112	25.3	141	24.8
36.4+	112	25.3	147	25.8
Family history of prostate cancer				
No family history	398	89.8	466	81.9
Family history	45	10.2	103	18.1
Body Mass Index 10 years ago				
Underweight/normal range	185	41.8	234	41.1
Overweight	195	44.0	272	47.8
Obese	63	14.2	63	11.1
Smoking status				
Never smoker	143	32.3	195	34.3
Former smoker	257	58.0	325	57.1
Current smoker	43	9.7	49	8.6
Index of relative socioeconomic disadvantage				
Group 1 (most disadvantaged)	27	6.1	27	4.7
Group 2	72	16.3	86	15.1
Group 3	91	20.5	101	17.8
Group 4	82	18.5	115	20.2
Group 5 (least disadvantaged)	171	38.6	240	42.2
Energy intake from food 10 years ago (kJ/day)				
0–7,513	110	24.8	148	26.0
7,514–9,261	111	25.1	133	23.4
9,262–11,531	111	25.1	142	25.0
11,532+	111	25.1	146	25.7
Years in occupation with heavy to very heavy physical demands				
0	200	45.1	245	43.1
1–3.9	62	14.0	81	14.2
4–11.9	76	17.2	101	17.8
12–27.9	53	12.0	73	12.8
28+	52	11.7	69	12.1

Table 2 Association between recreational physical activity in specific age periods and over the lifetime and prostate cancer risk in the Western Australia Prostate Health Study

Categories of MET-hours per week	Controls ($n=443$)	Cases ($n=569$)	OR (95% CI)[a]	AOR (95% CI)[b]
12–18 years of age				
Total physical activity				
0–7.9	107	109	1.00 (Reference)	1.00 (Reference)
8–26.9	114	136	1.25 (0.86–1.83)	1.13 (0.78–1.66)
27–59.9	110	162	1.45 (1.00–2.12)	1.41 (0.97–2.05)
60+	112	162	1.46 (1.00–2.11)	1.36 (0.94–1.98)
p_{Trend}			0.042	0.057
Moderate-intensity physical activity				
0	234	271	1.00 (Reference)	1.00 (Reference)
0.1–9.9	106	146	1.16 (0.85–1.57)	1.11 (0.80–1.54)
10+	103	152	1.26 (0.92–1.71)	1.27 (0.90–1.79)
p_{Trend}			0.129	0.164
Vigorous-intensity physical activity				
0–4.9	110	122	1.00 (Reference)	1.00 (Reference)
5–21.9	111	150	1.18 (0.83–1.69)	1.13 (0.78–1.65)
22–49.9	111	146	1.16 (0.81–1.67)	1.08 (0.74–1.57)
50+	111	151	1.18 (0.83–1.70)	1.03 (0.70–1.52)
p_{Trend}			0.414	0.964
19–34 years of age				
Total physical activity				
0–5.9	107	147	1.00 (Reference)	1.00 (Reference)
6–19.9	118	151	0.84 (0.59–1.21)	0.82 (0.57–1.19)
20–40.9	108	132	0.91 (0.64–1.31)	0.71 (0.47–1.05)
41+	110	139	0.90 (0.63–1.29)	0.67 (0.44–1.01)
p_{Trend}			0.611	0.044
Moderate-intensity physical activity				
0	139	173	1.00 (Reference)	1.00 (Reference)
0.1–10.9	151	180	0.91 (0.66–1.25)	0.91 (0.65–1.28)
11+	153	216	1.09 (0.80–1.49)	1.06 (0.75–1.51)
p_{Trend}			0.545	0.693
Vigorous-intensity physical activity				
0–0.9	116	161	1.00 (Reference)	1.00 (Reference)
1–8.9	101	151	1.08 (0.76–1.54)	0.97 (0.67–1.41)
9–22.9	116	121	0.74 (0.52–1.06)	0.63 (0.43–0.93)
23+	110	136	0.90 (0.63–1.28)	0.67 (0.45–1.01)
p_{Trend}			0.228	0.013
35–49 years of age				
Total physical activity				
0–5.9	115	152	1.00 (Reference)	1.00 (Reference)
6–17.9	113	126	0.74 (0.51–1.07)	0.77 (0.52–1.14)
18–34.9	102	141	0.82 (0.57–1.19)	0.98 (0.65–1.49)
35+	113	150	0.89 (0.62–1.28)	0.94 (0.61–1.46)
p_{Trend}			0.898	0.924
Moderate-intensity physical activity				
0–0.9	114	151	1.00 (Reference)	1.00 (Reference)
1–9.9	110	101	0.64 (0.44–0.92)	0.70 (0.47–1.04)
10–25.9	109	174	1.13 (0.80–1.60)	1.27 (0.87–1.87)
26+	110	143	0.93 (0.65–1.32)	1.04 (0.69–1.58)
p_{Trend}			0.597	0.329
Vigorous-intensity physical activity				

Table 2 (continued)

Categories of MET-hours per week	Controls ($n=443$)	Cases ($n=569$)	OR (95% CI)[a]	AOR (95% CI)[b]
0	198	291	1.00 (Reference)	1.00 (Reference)
0.1–7.4	122	107	0.56 (0.40–0.77)	0.54 (0.38–0.77)
7.5+	123	171	0.91 (0.68–1.23)	0.87 (0.61–1.23)
p_{Trend}			0.299	0.258
50 + years of age				
Total physical activity				
0.7.4	110	140	1.00 (Reference)	1.00 (Reference)
7.5–23.4	111	163	1.15 (0.77–1.72)	1.27 (0.86–1.88)
23.5–43.9	113	134	1.08 (0.73–1.62)	0.96 (0.63–1.47)
44+	109	132	0.98 (0.66–1.47)	0.98 (0.62–1.55)
p_{Trend}			0.725	0.636
Moderate-intensity physical activity				
0–3.9	113	140	1.00 (Reference)	1.00 (Reference)
4–15.9	107	154	1.22 (0.86–1.74)	1.34 (0.91–1.99)
16–33.9	112	135	1.02 (0.71–1.46)	1.11 (0.73–1.67)
34+	111	140	1.09 (0.76–1.56)	1.18 (0.77–1.82)
p_{Trend}			0.893	0.677
Vigorous-intensity physical activity				
0	260	351	1.00 (Reference)	1.00 (Reference)
0.1–9.3	91	101	0.86 (0.62–1.20)	0.83 (0.58–1.19)
9.4+	92	117	0.96 (0.69–1.32)	0.91 (0.64–1.31)
p_{Trend}			0.644	0.503
Lifetime				
Total physical activity				
0–11.9	109	133	1.00 (Reference)	1.00 (Reference)
12–22.9	107	146	1.11 (0.77–1.59)	1.04 (0.72–1.50)
23–38.4	116	128	0.87 (0.60–1.25)	0.80 (0.55–1.16)
38.5+	111	162	1.18 (0.83–1.69)	1.10 (0.77–1.59)
p_{Trend}			0.613	0.893
Moderate-intensity physical activity				
0–4.4	110	134	1.00 (Reference)	1.00 (Reference)
4.5–11.4	111	154	1.15 (0.81–1.64)	1.13 (0.78–1.63)
11.5–22.9	115	141	1.02 (0.71–1.46)	1.04 (0.72–1.51)
23+	107	140	1.13 (0.79–1.62)	1.16 (0.79–1.72)
p_{Trend}			0.685	0.564
Vigorous-intensity physical activity				
0–2.9	103	127	1.00 (Reference)	1.00 (Reference)
3–8.9	116	160	1.11 (0.78–1.59)	1.03 (0.71–1.49)
9–18.9	116	130	0.85 (0.59–1.23)	0.77 (0.52–1.12)
19+	108	152	1.07 (0.74–1.54)	0.97 (0.66–1.44)
p_{Trend}			0.907	0.541

AOR adjusted odds ratio, *MET* metabolic equivalent, *OR* odds ratio

[a]Adjusted for age group

[b]Adjusted for age group, alcohol consumption 10 years ago, family history of prostate cancer, body mass index 10 years ago, smoking status, index of relative socioeconomic disadvantage, energy intake 10 years ago, lifetime occupational physical activity, and total recreational physical activity in all previous age periods. Moderate- and vigorous-intensity physical activity and resistance training were mutually adjusted

for resistance training and the risks of medium-to-high grade and low-grade prostate cancers (Online Resource 2).

Discussion

In this population-based case–control study, we observed that recreational physical activity, specifically vigorous-intensity physical activity performed in early adulthood, was associated with a reduced risk of prostate cancer. Recreational physical activity in other age periods and average physical activity levels over the lifetime were not associated with prostate cancer risk. Weight training performed from early adulthood onwards showed a small but consistent inverse association with prostate cancer risk. There was no strong evidence that physical activity was differentially associated with the risks of low-grade and medium-to-high grade prostate cancers.

In this study, we found that physical activity in early adulthood was associated with a lower risk of prostate cancer. While it is possible that this is a chance finding, this result is consistent with previous research. A 2011 meta-analysis concluded that physical activity during the age periods 20–45 years and 45–65 years was associated with significantly lower prostate cancer risk [summary risk ratios = 0.93 (95% CI 0.89–0.97) and 0.91 (95% CI 0.86–0.97)], while, as with our results, physical activity before the age of 20 and after the age of 65 was not associated with prostate cancer risk [4]. It is biologically plausible that exposures (such as physical activity) experienced in early adulthood may influence prostate cancer risk as there is evidence that pre-neoplastic and neoplastic prostate alterations often develop during this time [27]. Relatively few studies have investigated whether there are critical age periods in which physical activity may confer a greater benefit in prostate cancer risk reduction, and

Table 3 Association between weight training and prostate cancer risk in the Western Australia Prostate Health Study

Categories of MET-hours per week	Controls (*n* = 443)	Cases (*n* = 569)	OR (95% CI)[a]	AOR (95% CI)[b]
12–18 years of age				
0	417	526	1.00 (Reference)	1.00 (Reference)
0.1–4.4	13	22	1.29 (0.64–2.62)	1.29 (0.62–2.69)
4.5+	13	21	1.30 (0.64–2.65)	1.25 (0.59–2.65)
p_{Trend}			*0.340*	*0.426*
19–34 years of age				
0	401	520	1.00 (Reference)	1.00 (Reference)
0.1–4.9	20	29	0.95 (0.53–1.73)	1.00 (0.54–1.87)
5+	22	20	0.68 (0.37–1.28)	0.71 (0.37–1.38)
p_{Trend}			0.265	0.379
35–49 years of age				
0	408	533	1.00 (Reference)	1.00 (Reference)
0.1–5.9	18	18	0.66 (0.34–1.31)	0.64 (0.31–1.33)
6+	17	18	0.72 (0.36–1.44)	0.68 (0.32–1.41)
p_{Trend}			0.189	0.153
50+ years of age				
0	398	524	1.00 (Reference)	1.00 (Reference)
0.1–5.4	22	25	0.88 (0.49–1.59)	0.90 (0.48–1.67)
5.5+	23	20	0.58 (0.31–1.09)	0.58 (0.30–1.14)
p_{Trend}			0.095	0.125
Lifetime				
0	356	456	(Reference)	1.00 (Reference)
0.1–1.4	42	62	1.07 (0.70–1.64)	1.07 (0.69–1.65)
1.5+	45	51	0.79 (0.51–1.23)	0.78 (0.50–1.23)
p_{Trend}			0.428	0.409

AOR adjusted odds ratio, *MET* metabolic equivalent, *OR* odds ratio

[a]Adjusted for age group

[b]Adjusted for age group, alcohol consumption 10 years ago, family history of prostate cancer, body mass index 10 years ago, smoking status, index of relative socioeconomic disadvantage, energy intake 10 years ago, lifetime occupational physical activity, and total recreational physical activity in all previous age periods. Moderate- and vigorous-intensity physical activity and resistance training were mutually adjusted

further replication of our finding for early adulthood is needed.

In our study, we found small but consistent inverse associations between weight training performed in different age periods (19–34, 35–49, and > 50 years) and the risk of prostate cancer; however, the low prevalence of weight training meant that we had low statistical power and as a result none of these associations were statistically significant. While no previous studies have investigated the association between weight training and the risk of prostate cancer, it has been associated with lower all-cause mortality and cancer mortality [16, 17] and there is some evidence indicating resistance training may be inversely associated with reduced colon cancer risk [18]. Given the results of these studies and the minimal research on prostate cancer, the association between resistance training and the risk of prostate cancer warrants further investigation.

In this study, we also investigated whether intensity influences the association between physical activity and risk of prostate cancer, and whether physical activity was differentially associated with the risks of low-grade and medium-to-high grade prostate cancers. We found that vigorous-intensity physical activity during early adulthood was associated with lower risk of prostate cancer risk, but no association between moderate-intensity physical activity and prostate cancer risk was observed in any age period. The findings of previous studies concerning physical activity intensity and prostate cancer risk are inconsistent and it remains unclear whether intensity influences the association between physical activity and prostate cancer risk [7]. When looking at low-grade and medium-to-high grade prostate cancers separately, we found similar associations between recreational physical activity and risk. This finding differs from a recent meta-analysis which found that the inverse association between recreational activity and prostate cancer was limited to advanced/aggressive cancers [7].

This study had several strengths and limitations. As the physical activity information was collected through a self-reported questionnaire and was recalled over the lifetime (from early adolescence to the time of the study), exposure misclassification is possible. However, the varying associations observed for physical activity in different age periods suggest any exposure misclassification is likely to have been non-differential, as it seems unlikely that cases and controls would differentially recall their physical activity levels in some age periods but not others. The fact that the study questionnaire asked about a wide range of risk factors, and that physical activity was not a well-known cancer risk factor at the time of the study, also reduces the likelihood that recall bias is an explanation for the observed results. Our sensitivity analyses indicate that any potential non-differential exposure misclassification had minimal effect on the observed results. A key strength of the current study was the use of a comprehensive measure of lifetime physical activity which allowed us to investigate the associations between physical activity at different intensities, types and age periods, and risk of prostate cancer. Our study was also a population-based study and we had information on a wide range of confounders, which allowed us to adjust for variables that may influence the association between recreational physical activity and the risk of prostate cancer.

In conclusion, in this study, we found that vigorous-intensity physical activity performed in early adulthood was associated with a reduced risk of prostate cancer. We also report preliminary evidence that weight training may be associated with prostate cancer risk and recommend further research on this topic.

Acknowledgments The Prostate Health Study was funded by a Western Australian Health Promotion Foundation (Healthway) Research Project Grant and the BUPA Foundation. Lin Fritschi and Terry Boyle were supported by the Australian National Health and Medical Research Council (Fellowship #37614900 to LF; Early Career Fellowship #1072266 to TB). The authors acknowledge Professor Anna Timperio's contribution to the Prostate Health Study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

1. Attard G, Parker C, Eeles RA, Schröder F, Tomlins SA, Tannock I et al (2016) Prostate cancer. The Lancet 387:70–82
2. Bostwick DG, Burke HB, Djakiew D, Euling S, Ho S-m, Landolph J et al (2004) Human prostate cancer risk factors. Cancer 101:2371–2490
3. Australian Institute of Health and Welfare (2017) Prostate cancer. Australian Institute of Health and Welfare, Canberra
4. Liu YP, Hu FL, Li DD, Wang F, Zhu L, Chen WY et al (2011) Does physical activity reduce the risk of prostate cancer? A systematic review and meta-analysis. Eur Urol 60:1029–1044
5. Shephard RJ (2017) Physical activity and prostate cancer: an updated review. Sports Med 47:1055–1073
6. Young-McCaughan S (2012) Potential for prostate cancer prevention through physical activity. World J Urol 30:167–179
7. Benke IN, Leitzmann MF, Behrens G, Schmid D (2018) Physical activity in relation to risk of prostate cancer: a systematic review and meta-analysis. Ann Oncol 29:1154–1179
8. Boyle T (2012) Physical activity and colon cancer: timing, intensity and sedentary behavior. Am J Lifestyle Med 6:204–215
9. Lynch BM, Neilson HK, Friedenreich CM (2011) Physical activity and breast cancer prevention. Recent Results Cancer Res 186:13–42

10. Littman AJ, Kristal AR, White E (2006) Recreational physical activity and prostate cancer risk (United States). Cancer Causes Control 17:831–841
11. Moore SC, Peters TM, Ahn J, Park Y, Schatzkin A, Albanes D et al (2009) Age-specific physical activity and prostate cancer risk among White men and Black men. Cancer 115:5060–5070
12. Pierotti B, Altieri A, Talamini R, Montella M, Tavani A, Negri E et al (2005) Lifetime physical activity and prostate cancer risk. Int J Cancer 114:639–642
13. Bairati I, Larouche R, Meyer F, Moore L, Fradet Y (2000) Lifetime occupational physical activity and incidental prostate cancer (Canada). Cancer Causes Control 11:759–764
14. Orsini N, Bellocco R, Bottai M, Pagano M, Andersson SO, Johansson JE et al (2009) A prospective study of lifetime physical activity and prostate cancer incidence and mortality. Br J Cancer 101:1932–1938
15. Leitzmann MF (2011) Physical activity and genitourinary cancer prevention. Recent Results Cancer Res 186:43–71
16. Stamatakis E, Lee I-M, Bennie J, Freeston J, Hamer M, O'Donovan G et al (2018) Does strength promoting exercise confer unique health benefits? A pooled analysis of eleven population cohorts with all-cause, cancer, and cardiovascular mortality endpoints. Am J Epidemiol 187:1102–1112
17. Kraschnewski JL, Sciamanna CN, Poger JM, Rovniak LS, Lehman EB, Cooper AB et al (2016) Is strength training associated with mortality benefits? A 15 year cohort study of US older adults. Prev Med 87:121–127
18. Boyle T, Bull F, Fritschi L, Heyworth J (2012) Resistance training and the risk of colon and rectal cancers. Cancer Causes Control 23:1091–1097
19. Fritschi L, Glass DC, Tabrizi JS, Leavy JE, Ambrosini GL (2007) Occupational risk factors for prostate cancer and benign prostatic hyperplasia: a case–control study in Western Australia. Occup Environ Med 64:60–65
20. Ambrosini GL, Fritschi L, de Klerk NH, Mackerras D, Leavy J (2008) Dietary patterns identified using factor analysis and prostate cancer risk: a case control study in Western Australia. Ann Epidemiol 18:364–370
21. Chasan-Taber L, Erickson JB, McBride JW, Nasca PC, Chasan-Taber S, Freedson PS (2002) Reproducibility of a self-administered lifetime physical activity questionnaire among female college alumnae. Am J Epidemiol 155:282–289
22. Kriska AM, Sandler RB, Cauley JA, LaPorte RE, Hom DL, Pambianco G (1988) The assessment of historical physical activity and its relation to adult bone parameters. Am J Epidemiol 127:1053–1063
23. De Vera MA, Ratzlaff C, Doerfling P, Kopec J (2010) Reliability and validity of an internet-based questionnaire measuring lifetime physical activity. Am J Epidemiol 172:1190–1198
24. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor-Locke C et al (2011) 2011 Compendium of physical activities: a second update of codes and MET values. Med Sci Sports Exerc 43:1575–1581
25. Greenland S, Pearl J, Robins JM (1999) Causal diagrams for epidemiologic research. Epidemiology 10:37–48
26. Australian Bureau of Statistics (2013) Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA), Australia, 2011. Catalogue Number 2033.0.55.001. Australian Bureau of Statistics, Canberra
27. Sutcliffe S, Colditz GA (2013) Prostate cancer: is it time to expand the research focus to early-life exposures? Nat Rev Cancer 13:208–518

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