Cancers in Australia in 2010 attributable to insufficient physical activity

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Regular physical activity is important for optimal health and significant benefits occur from even modest amounts of physical activity,[1] including lower cancer rates.[2] There is consistent evidence from a systematic review and meta-analysis of cohort studies that physical activity is associated with a reduced risk of colon cancer.[3] Research has also consistently demonstrated links between physical activity and reduced risk of post-menopausal breast cancer[4] and endometrial cancer.[5] The World Cancer Research Fund (WCRF) has concluded that there is "convincing" or "probable" evidence that insufficient physical activity causes cancers of the colon, post-menopausal breast and endometrium.[6]

The most recent Australian guidelines for physical activity and sedentary behaviour were released in February 2014.[7] They recommend that adults perform at least 150 minutes of moderate intensity physical activity or 75 minutes of vigorous intensity physical activity per week to help improve blood pressure, cholesterol, heart health and muscle and bone strength. This should be increased to 300 minutes of moderate intensity physical activity or 150 minutes of vigorous intensity physical activity per week to reap greater health benefits and help to prevent cancer and unhealthy weight gain.[7]

The National Guidelines defines 60 minutes of moderate intensity physical activity on most days of the week (assumed 5 days) as a sufficient level to help prevent cancer. We aimed to estimate the fraction and number of cancers of the colon, post-menopausal breast and endometrium arising in the Australian population in 2010 that were attributable to failing to meet this target. We assumed that lower levels of physical activity conferred some benefit, but less than optimum.

Methods

Physical activities are often categorised by domain, e.g. occupational or recreational, as well as by type, frequency, duration and intensity. Different types of activity are commonly equated through metabolic equivalents (METs). One MET is considered to represent resting energy expenditure, about 3.5 mL O_2/kg/min when measured in terms of oxygen consumption. Because any form of activity requires increased oxygen consumption, activities can be quantified in terms of multiples of this resting oxygen consumption (e.g. an activity that requires four times the oxygen consumption of rest would be defined as 4 METS). Moderate activity consumes about 3–6 METS,[8] depending upon fitness level.[9] We followed

Abstract

Objectives: To estimate the proportion and numbers of cancers occurring in Australia in 2010 attributable to insufficient levels of physical activity.

Methods: We estimated the population attributable fraction (PAF) of cancers causally associated with insufficient physical activity (colon, post-menopausal breast and endometrium) using standard formulae incorporating prevalence of insufficient physical activity (<60 minutes at least 5 days/week), relative risks associated with physical activity and cancer incidence. We also estimated the proportion change in cancer incidence (potential impact fraction [PIF]) that may have occurred assuming that everyone with insufficient activity levels increased their exercise by 30 minutes/week.

Results: An estimated 1,814 cases of colon, post-menopausal breast and endometrial cancer were attributable to insufficient levels of physical activity: 707 (6.5%) colon; 971 (7.8%) post-menopausal breast; and 136 (6.0%) endometrial cancers. If those exercising below the recommended level had increased their activity level by 30 minutes/week, we estimate 314 fewer cancers (17% of those attributable to insufficient physical activity) would have occurred in 2010.

Conclusions: More than 1,500 cancers were attributable to insufficient levels of physical activity in the Australian population.

Implications: Increasing the proportion of Australians who exercise could reduce the incidence of several common cancers.

Key words: population attributable fraction, cancer, risk factor, exercise, potential impact fraction

the approach of a UK PAF project[10] and assumed, conservatively, that moderate activity is equivalent to 6 METS. It follows that exercise of moderate intensity of 60 minutes duration consumes 6 MET-hours. Complying with the National Guidelines equates to 300 minutes or 30 MET-hours per week.

Relative risk estimates

For colon cancer and post-menopausal breast cancer, we used relative risks reported in the WCRF Continuous Update for Colorectal Cancer[11] and the WCRF Second Expert Panel Report,[6] respectively. Because the WCRF did not publish a dose-response summary relative risk for endometrial cancer, we sourced the summary relative risk from a dose-response meta-analysis of three cohort studies undertaken by Keum and colleagues[12] (Table 1).

The increase in risk for a decrease of 1 MET-hour of recreational physical activity per week was estimated by assuming a log-linear relationship between exposure and risk, so that:

Risk per 1 MET-hour per week = ln(1/RR$_x$)/x

where x is the exposure level (in MET-hours per week) and RR$_x$ the relative risk for x MET-hours per week.

The increases in risk for a decrease of 1 MET-hour of recreational physical activity per week for colon cancer, post-menopausal breast cancer and endometrial cancer were 4.041e-3, 4.351e-3 and 3.35e-3 respectively.

Exposure prevalence estimates

The latent period between physical inactivity and onset of cancer is not known. In the WCRF systematic review of colon cancer, follow-up periods in cohort studies that reported dose-response MET-hours, ranged from 1.6 years to 16 years, with an average of 9.2 years.[11] For post-menopausal breast cancer, follow-up periods ranged from 4.7 years to 7.3 years, with an average follow-up of 5.7 years;[13] and for endometrial cancer, there was an average follow-up of 8.8 years (ranging from 6.6 years to 11.0 years).[12] We

used prevalence data from 2001 and cancer incidence data from 2010 to give a nominal latent period of about 10 years. To account for population ageing with time since exposure and the latent period, we used prevalence data for the age category that was 10 years younger than the corresponding cancer incidence age category (for example, cancer incidence in the 25–34 years age group in 2010 was attributed to insufficient physical activity in the 15–24 years age group in 2001).

We used data from the 2001 National Health Survey Confidentialised Unit Record Files[14] to estimate the deficit in physical activity against the recommended guidelines for cancer prevention (300 minutes of moderate activity or about 30 MET-hours per week), by sex and age categories.

The National Health Survey did not directly report the proportion of people undertaking different amounts of activity by age and sex; however, data reported in the National Health Survey Confidentialised Unit Record Files included:

- the mean number of minutes individuals who reported walking, moderate or vigorous exercise spent participating in that activity per fortnight, by sex and age categories; we converted this to mean minutes per week by dividing by 2 (online supplementary file Table S1); and

- the proportion of people (by age and sex categories) doing different combinations of types of exercise (no exercise, walking only, moderate exercise only, vigorous exercise only, walking and moderate, walking and vigorous, moderate and vigorous, walking plus moderate and vigorous).

To estimate the proportion of people exercising at different levels, we first estimated the average total minutes individuals reporting each activity combination spent exercising per week (online supplementary file: Table S2). To do this, we assumed that people who reported two types of activity performed each for half the average duration for each activity and that those who reported all three types

of activity performed each for one-third of the average duration. In sensitivity analyses, we assumed that people who performed multiple types of activity in a week spent the average time on each activity type. For example, for people reporting the exercise combination of walking and moderate activity, we simply summed the national average durations for each activity.

We applied a weighting (x2) to vigorous activity to account for the higher intensity level of metabolic activity.[7] The estimated average total minutes of activity for each combination was then converted to MET-hours per week on the assumption that 60 minutes of moderate activity constitutes 6 MET-hours. We conducted a sensitivity analysis assuming that 60 minutes of moderate activity constitutes 3 MET-hours rather than 6 MET-hours.

For each age, sex and exercise type category, we calculated the deficit from the recommended 30 MET-hours per week (hereafter described as 'insufficient physical activity') and categorised this as no deficit, >0-<6 MET-hour deficit, 6-<12 MET-hour deficit, 12-<24 MET-hour deficit, and 24-30 MET-hour deficit. For each sex and age-category, the proportion of people in each MET-hour deficit category was then totalled (Table 2). Relative risks were calculated for each Met-hour deficit category for each age group using the following formula:

*Relative Risk = EXP(Increase in log risk per MET-hour deficit per week * deficit in MET-hours per week)*

where the deficit in MET-hours per week is the mid-point of the MET-hour deficit categories.

Statistical analysis

The population attributable fraction (PAF) was calculated using the standard formula:[15]

$$PAF = \frac{\Sigma(p_x \times ERR_x)}{1 + \Sigma(p_x \times ERR_x)}$$

where p_x is the proportion of the population in each exercise category x and ERR_x is the excess relative risk (RR-1) for each exercise category x.

To obtain the number of cancers attributable to a deficit in physical activity levels, the PAF was multiplied by the number of incident cancers at each site in 2010[16] for each age and sex category. The number of colon, post-menopausal breast and endometrial cancers attributable to a deficit in physical activity levels was then summed and expressed as a percentage of the total number of all incident cancers (excluding basal cell and squamous

Table 1: Relative risks for recreational physical activity and colon, breast (post-menopause) and endometrial cancer.

Cancer site	Source	Relative risk
Colon	WCRF CUP (2010)[11]	0.98 (95%CI 0.96-1.00) per 5 MET-hours per week
Breast (post-menopause)	WCRF Second Expert Panel (2007)[6]	0.97 (95%CI 0.95-0.99) per 7 MET-hours per week
Endometrium	Dose-response meta-analysis Keum et al (2013)[12]	0.99 (95%CI 0.98-1.00) per 3 MET-hours per week

cell carcinoma of the skin) recorded among adults aged 25 and over in Australia in 2010.

Potential impact of increasing physical activity levels in the Australian population

We estimated the number of cancers in 2010 that may have been prevented by proposing a hypothetical situation in which all those exercising below the recommended level increased the amount of time they spent exercising at moderate intensity by 30 minutes (3 MET-hours) per week. To do this, we reduced the mid-point of each exercise deficit category by 3 MET-hours (e.g. the mid-point of the 6-<12 MET-hour deficit category was reduced from 9 to 6), and then used the relative risk per MET-hour deficit to estimate the new relative risk for each MET/hr deficit category. We then calculated the potential impact fraction (PIF) using the formula of Barendregt and Veerman:[17]

$$PIF = \frac{\sum_{x=1}^{n} p_x RR_x - \sum_{x=1}^{n} p_x RR_x^*}{\sum_{x=1}^{n} p_x RR_x}$$

where p_x is the proportion of population in each age and sex category x, RR_x is the relative risk for that category and RR_x^* is the new relative risk for each MET/hr deficit category when the mid-point of each category was reduced by 3 MET-hours.

The PIF is the proportional difference between the observed number of cancers and the number expected under the alternative scenario. Finally, we calculated the number of colon, post-menopausal breast and endometrial cancers that would have not occurred among people aged 25 and over in Australia in 2010 under the alternative scenario.

The estimated numbers and proportions of cancers attributed to insufficient physical activity levels are presented in Table 3. In 2010, 27,294 diagnoses of cancers of the colon, post-menopausal breast and endometrium in Australians >25 years, of which we estimated 1,814 (6.6%) were attributable to insufficient physical activity; 707 (6.5%) colon cancer cases, 971 post-menopausal breast cancer cases (6.8% of all breast cancers, 7.8% of post-menopausal breast cancer cases [45+ years]), and 136 (6.0%) endometrial cancer cases. This corresponds to 1.6% of all cancer cases (excluding basal cell carcinoma and squamous cell carcinoma of the skin) in Australian adults aged >25 years in 2010 (0.5% in men and 2.9% in women).

Sensitivity analysis

When the average times per week spent undertaking multiple types of activity were simply summed (rather than proportionally split as in the primary analyses), overall activity levels increased. Consequently, the estimated number of cancer cases attributable to insufficient levels of physical activity dropped to 610 (5.6%) colon cancers, 821 (5.8%) post-menopausal breast cancers (5.8% of all breast cancers, 6.6% of post-menopausal breast cancers [45+ years]) and 113 (5.0%) endometrial cancers.

Our sensitivity analysis, assuming that 60 minutes of moderate activity constitutes 3 MET-hours, resulted in higher estimates of the PAF for colon cancer (8.2%), breast cancer (7.7%) and endometrial cancer (6.8%); with the total number of excess cancer cases increasing from 1,814 to 2,131.

Potential impact of increasing physical activity levels in the Australian population

Reducing the 'average' deficit in the activity categories by 3 MET-hours/week would have had a modest impact on cancer incidence. If everyone who did insufficient physical activity had increased their exercise levels by 3 MET-hours/week, about 314 fewer cancers would have been diagnosed (PIF 1.2%). This represents 17% (314/1,814) of all cancers attributable to insufficient physical activity. The proportional impacts were similar across all three cancer types.

Discussion

We estimate that 1,814 cases of colon, post-menopausal breast and endometrial cancer that occurred in Australian adults in 2010 could be attributed to insufficient levels of physical activity, corresponding to PAFs of 6.5% for colon cancer, 7.8% post-menopausal breast cancer (6.8% of all breast cancers) and 6.0% for endometrial cancer.

The estimates of PAF were not especially sensitive to the values of energy expenditure used in the calculations of 'activity deficit' with the major influence being the high prevalence of physical inactivity (or activity at less than recommended levels) in the population. These attributable fractions are higher than those reported for the UK[10] for cancers occurring in 2010 (5.3% for colon, 3.4% for breast and 3.8% for endometrium); however, the UK study considered a sufficient level of activity as 15 MET-hrs/week, the UK Department of Health target,[18] which is half the level for cancer prevention recommended by Australian guidelines. Not unexpectedly,

Results

The estimated proportion of Australian adults meeting the physical activity guidelines for cancer prevention was only 4% for men and less than 1.0% for women (Table 2). The proportion of women doing little or no exercise increased steadily with age, ranging from 24% (15–24 years) to 55% (75+ years). A similar pattern was seen for men, although there appeared to be an increase in activity after retirement age. Of note was the large decline in activity levels between the 15–24 and 25–34 year age groups, particularly for men, suggesting this group might be an appropriate target for intervention activities.

Table 2: Estimated proportion (%) of adult men and women in the Australian population performing physical activity at the given level (against the recommended 30 MET-hours per week) (National Health Survey, 2001).[a]

	15-24 yrs	25-34 yrs	35-44 yrs	45-54 yrs	55-64 yrs	65-74 yrs	75+ yrs	15+ years
Males								
24-30 MET-hrs deficit	18.1	26.2	32.2	31.1	34.4	29.2	43.0	29.0
12-<24 MET-hrs deficit	37.2	44.7	47.2	54.3	0.0	0.0	0.0	27.4
6-<12 MET-hrs deficit	14.7	24.9	17.2	12.1	64.3	29.5	45.2	34.3
>0-<6 MET-hrs deficit	19.8	4.3	3.4	0.0	1.3	40.7	11.9	5.4
No deficit	10.2	0.0	0.0	2.5	0.0	0.6	0.0	4.0
Females								
24-30 MET-hrs deficit	24.1	25.8	30.3	30.1	30.7	37.6	54.6	30.9
12-<24 MET-hrs deficit	62.8	64.6	63.5	65.5	8.1	0.0	29.6	57.5
6-<12 MET-hrs deficit	10.3	7.6	5.0	4.4	58.1	59.9	15.7	10.2
>0-<6 MET-hrs deficit	2.8	2.0	1.3	0.0	2.5	0.6	0.0	1.4
No deficit	0.0	0.0	0.0	0.0	0.6	2.0	0.0	0.0

a: Derived from data from the 2001 National Health Survey Expanded Confidentialised Unit Record File, RADL.[14]

the proportion of Australians meeting these cancer prevention guidelines in 2001 was low; however, our dose–response calculations of the PAF took into account any exercise performed under the recommended level. Another factor that may have contributed to the very low prevalence of Australians meeting the physical activity guidelines for cancer prevention in our analysis is the way in which physical activity data are reported. The National Health Survey Confidentialised Unit Record Files only report the proportion of people by age-group and sex who participate in any given activity, and then report the mean number of minutes spent performing that activity. For the purposes of estimating the PAF, it would be more informative to report the proportions of Australians in categories of time spent in moderate and vigorous activity, respectively (e.g. 'none', '1–29/mins/week', '30–59 mins/week', '60–89 mins/week', etc). Ideally, future investigations would have access to more complete data to enable better estimates.

Other studies that have reported PAFs for different populations have generally undertaken dichotomous comparisons of active vs. inactive adults, however defined,[19-22] resulting in much higher PAFs. Such estimates are not directly comparable with our findings using dose–response relative risks, which assume that even low levels of physical activity confer some benefits. We contend that this approach generates more plausible estimates of effect than a simple categorical analysis in which it is assumed there is no benefit for failing to meet the guideline, even among people undertaking some physical activity. We also used summary relative risks from cohort studies only, which are less likely to be affected by information biases than risk estimates from case-control studies, but are typically more conservative in their estimates of benefits of physical activity.

These analyses highlight the relative paucity of national data describing durations (as opposed to categories) of different types of physical activity among Australians. We used the available data to estimate the distribution of MET-hours/week of activity within categories of age and sex; however, this required us to make assumptions about certain activity patterns, especially for people engaging in two or more forms of physical activity. Our approach was to reduce their time spent on each separate activity proportionately. It is possible that this approach was overly conservative, and so we performed sensitivity analyses allowing a more liberal summation of activity levels. Even so, this made little substantive difference to the estimates: most Australians perform insufficient activity, and the estimates of the cancer burden changed little regardless of how activity levels were summed.

We were limited to considering recreational physical activity only, and were unable to consider the potential adverse effects of sedentary behaviour separately. Sedentary behaviour may be particularly important for colon, endometrial and breast cancer risk,[23,24] with a recent meta-analysis reporting increased risks associated with high levels of total sitting time.[25]

Notably, our calculations of the fraction of cancers attributable to physical inactivity should be independent of the effects of overweight/obesity. We used relative risk estimates that were adjusted for the potentially confounding effects of other exposures, including overweight/obesity, although it is possible that some residual confounding remains.

To avoid potentially subjective assessments of causality, we restricted our analyses to cancers causally associated with physical

Table 3: Population attributable fraction (PAF) and estimated number of cancers diagnosed in Australia in 2010 attributable to insufficient levels of physical activity.

Age at outcome[a]	Colon [C18, C19][b]			Breast (post-menopausal) [C50][b]			Endometrium [C54, C55][b]			All cancers[c]	
	PAF	Obs.	Exc.	PAF	Obs.	Exc.	PAF	Obs.	Exc.	Obs.	Exc.
Males											
25-34 yrs	5.4	37	2							1,042	2
35-44 yrs	6.9	134	9							2,214	9
45-54 yrs	7.4	469	35							6,632	35
55-64 yrs	7.5	1187	89							16,279	89
65-74 yrs	6.0	1,817	109							19,513	109
75-84 yrs	4.7	1,557	73							14,520	73
85+	6.3	498	32							4,968	32
Total		5,699	349							65,168	349
PAF$_{aw}$	6.1									PAF$_{aw}$=	0.5
Females											
25-34 yrs	7.4	40	3		258		6.1	19	1	1,401	4
35-44 yrs	7.5	134	10		1,420		6.3	103	7	3,637	17
45-54 yrs	7.8	422	33	8.4	3,385	284	6.5	362	24	7,812	341
55-64 yrs	7.9	908	72	8.5	3,893	330	6.6	721	48	11,042	450
65-74 yrs	6.0	1,346	80	6.4	2,845	182	5.0	556	28	11,073	290
75-84 yrs	6.2	1,522	94	6.6	1,617	107	5.1	355	18	9,819	219
85+	8.4	794	66	9.0	756	68	7.0	139	10	5,166	144
Total		5,166	358		14,174	971		2,255	136	49,950	1,465
PAF$_{aw}$	6.9			6.8[d] 7.8[e]			6.0			PAF$_{aw}$=	2.9
Persons											
25-34 yrs		77	5		258			19	1	2,443	6
35-44 yrs		268	19		1420			103	7	5,851	26
45-54 yrs		891	68		3,385	284		362	24	14,444	376
55-64 yrs		2,095	161		3,893	330		721	48	27,321	539
65-74 yrs		3,163	189		2,845	182		556	28	30,586	399
75-84 yrs		3,079	167		1,617	107		355	18	24,339	292
85+		1,292	98		756	68		139	10	10,134	176
Total		10,865	707		14,174	971		2,255	136	115,118	1,814
PAF$_{aw}$	6.5			6.8[d] 7.8[e]			6.0			PAF$_{aw}$=	1.6

Abbreviations: Obs. = observed cancers in 2010; Exc. = excess cancers in 2010 attributable to insufficient physical activity; PAF = population attributable fraction (expressed as a percentage); PAFaw = age-weighted population attributable fraction (expressed as a percentage).

a: Prevalence data age groups are 10 years younger than cancer incidence age groups assuming a 10 year latent period.

b: International Classification of Diseases Code (ICD-10).

c: Excluding basal cell carcinoma and squamous cell carcinoma of the skin.

d: % of all breast cancers.

e: % of post-menopausal breast cancers (45+ years).

inactivity as determined by independent agencies (in this case WCRF) that have undertaken systematic and continual review of the evidence.[11,26-32] While we are aware of a growing literature describing possible associations with other cancers (e.g. oesophageal,[33] bladder,[34] gastric,[35] lung,[36] prostate[37] and pancreatic[38] cancer), the evidence to date has not been sufficient for WCRF or IARC to make a causal judgement, and so these cancers were not included in our analyses.

Maintaining a sufficient level of activity potentially offers people an opportunity to reduce their risk of colon, breast and endometrial cancers in addition to the numerous other chronic diseases associated with low physical activity. There are a number of biologically plausible pathways that may underlie a protective effect of higher levels of activity.

For colon cancer, postulated mechanisms include decreased gastrointestinal transit time (reducing exposure to carcinogens),[39] changes in serum levels of insulin and insulin-like growth factors (IGFs),[40] and alterations in the level of prostaglandin E2.[20] Regular physical activity significantly lowers insulin levels and enhances insulin sensitivity, independently of body mass index (BMI) – a measure of body fatness calculated as weight in kilograms divided by the square of height in meters (kg/m^2)[40,41] – and insulin increases the bioactivity of insulin-like growth factor I.[42,43] In laboratory studies and animal models, insulin is a growth factor for colon mucosal cells,[44] and physical activity causes a decrease in prostaglandin E2, which has been shown to stimulate colon cell proliferation in cell culture.[45] Indirect evidence for a role of prostaglandin E2 derives from the observation that aspirin and nonsteroidal anti-inflammatory drugs – inhibitors of prostaglandin synthesis – reduce risk of colon cancer.[46]

Proposed mechanisms for the benefits of physical activity on breast and endometrial cancer development include alterations in endogenous sex hormone levels (oestrogen, progesterone and androgens), insulin-mediated pathways, and maintenance of energy balance.[20,47] Regular physical activity has been shown to lower the levels of biologically available oestrogens, progesterone, and androgens[48,49] and to increase levels of circulating sex hormone binding protein.[50] Elevated serum levels of androgens and oestrogens in both pre- and post-menopausal women are associated with increased endometrial cancer risk,[51] and elevated circulating oestrogens in post-menopausal women are associated with increased breast cancer risk.[52] Regular physical activity also helps prevent or reduce obesity with consequent improvement in the metabolic profile (endogenous hormone and growth factor levels),[47] although it can be difficult to disentangle the independent effects of increasing physical activity and weight loss.

Sequential National Health Surveys have indicated that the proportion of Australians who are inactive or undertake only low levels of physical activity has declined from 73% in 2007-08 to 68% in 2011-12.[53] The 2011-12 Survey results indicated that undertaking sufficient levels of physical activity was more likely for people who rated their health as "excellent", who lived in areas of least disadvantage, and who had higher incomes and higher levels of education.[53] It is possible that those Australians who would stand to benefit most by engaging in higher levels of physical activity are not becoming more active, and this could have implications for future levels of cancer (and other chronic diseases) in the Australian community. While evidence on the effectiveness of workplace physical activity interventions is equivocal,[54] community-wide health education campaigns and school-based interventions have been shown to be effective,[55] supporting the role of multi-component interventions to successfully increase physical activity levels.

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PAF Project

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References

1. Vanhees L, De Sutter J, Gelada SN, Doyle F, Prescott E, Cornelissen V, et al. Importance of characteristics and modalities of physical activity and exercise in defining the benefits to cardiovascular health within the general population: Recommendations from the EACPR (Part I). *Eur J Prev Cardiol*. 2012;19(4):670-86.

2. Lemanne D, Cassileth B, Gubili J. The role of physical activity in cancer prevention, treatment, recovery, and survivorship. *Oncology (Williston Park)*. 2013;27(6):580-5.

3. Boyle T, Keegel T, Bull F, Heyworth J, Fritschi L. Physical activity and risks of proximal and distal colon cancers: A systematic review and meta-analysis. *J Natl Cancer Inst*. 2012;104(20):1548-61.

4. Friedenreich CM. Physical activity and breast cancer: Review of the epidemiologic evidence and biologic mechanisms. *Recent Results Cancer Res*. 2011;188:125-39.

5. Moore SC, Gierach GL, Schatzkin A, Matthews CE. Physical activity, sedentary behaviours, and the prevention of endometrial cancer. *Br J Cancer*. 2010;103(7):933-8.

6. World Cancer Research Fund. *Food, Nutrition, Physical Activity, and the Prevention of Cancer: A Global Perspective*. Washington (DC): American Institute for Cancer Research; 2007.

7. Department of Health. *Australia's Physical Activity and Sedentary Behaviour Guidelines for Adults (18-64 years)* [Internet]. Canberra (AUST): Commonwealth of Australia; 2014 [cited 2014 Feb 11]. Available from: http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-strateg-phys-act-guidelines#apaadult

8. World Health Organization. *Global Strategy of Diet, Physical Activity and Health. What is Moderate-intensity and Vigorous-intensity Physical Activity?* [Internet]. Geneva (CHE): WHO; 2015 [cited 2015 Jan 28]. Available from: http://www.who.int/dietphysicalactivity/physical_activity_intensity/en/#

9. Welk GJ. Introduction to Physical Activity Research. In: Welk GJ, editor. *Physical Activity Assessment for Health-related Research*. Champaign (IL): Human Kinetics Publishers; 2002. p. 3-18.

10. Parkin DM. Cancers attributable to inadequate physical exercise in the UK in 2010. *Br J Cancer*. 2011;105 Suppl 2:38-41.

11. World Cancer Research Fund. *Systematic Literature Review Continuous Update Project. The Associations between Food, Nutrition, Physical Activity and the Risk of Colorectal Cancer*; Washington (DC): American Institute for Cancer Research; 2010.

12. Keum N, Ju W, Lee DH, Ding EL, Hsieh CC, Goodman JE, et al. Leisure-time physical activity and endometrial cancer risk: Dose-response meta-analysis of epidemiological studies. *Int J Cancer*. 2013;135(3):682–94.

13. Agnoli CB, Canevari S, Casazza G, Colombo C, Fusconi E, Grioni S, et al. *Systematic Literature Review Report. The Associations between Food, Nutrition and Physical Activity and the Risk of Breast Cancer and Underlying Mechanisms. In support of the Revision of the World Cancer Research Fund International's Report on Diet, Nutrition, Physical Activity and Cancer*. London (UK): World Cancer Research Fund International; 2005.

14. Australian Bureau of Statistics. *2001 National Health Survey*. Expanded CURF, RADL. Findings Based on use of ABS CURF Data. Canberra (AUST): ABS; 2001.

15. Whiteman DC, Webb PM, Green AC, Neale RE, Fritschi L, Bain CJ et al. Cancers in Australia in 2010 attributable to modifiable factors: introduction and overview. *Aust NZ J Public Health*. 2015; 39:403-7.

16. Australian Institute of Health and Welfare. *Cancer Data. Pivot Table* [Internet]. Canberra (AUST): AIHW; 2015, [cited 2014 Jun 23]. Available from: http://www.aihw.gov.au/cancer-data/

17. Barendregt JJ, Veerman JL. Categorical versus continuous risk factors and the calculation of potential impact fractions. *J Epidemiol Community Health*. 2010;64(3):209-12.

18. United Kingdom Department of Health. *At Least Five a Week: Evidence on the Impact of Physical Activity and Its Relationship to Health. A Report from the Chief Medical Officer*. London (UK): UKDHS; 2004 [cited 2014 Feb 12]. Available from: http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4080994

19. Joubert J, Norman R, Lambert EV, Groenewald P, Schneider M, Bull F, et al. Estimating the burden of disease attributable to physical inactivity in South Africa in 2000. *S Afr Med J*. 2007;97(8 Pt 2):725-31.

20. Friedenreich CM, Neilson HK, Lynch BM. State of the epidemiological evidence on physical activity and cancer prevention. *Eur J Cancer*. 2010;46(14):2593-604.

21. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT, et al. Effect of physical inactivity on major non-communicable diseases worldwide: An analysis of burden of disease and life expectancy. *Lancet*. 2012;380(9838):219-29.

22. Hayes J, Richardson A, Frampton C. Population attributable risks for modifiable lifestyle factors and breast cancer in New Zealand women. *Intern Med J*. 2013;43(11):1198-204.

23. Shen D, Mao W, Liu T, Lin Q, Lu X, Wang Q, et al. Sedentary behavior and incident cancer: A meta-analysis of prospective studies. *PLoS One*. 2014;9(8):e105709.

24. Zhou Y, Zhao H, Peng C. Association of sedentary behavior with the risk of breast cancer in women: Update meta-analysis of observational studies. *Ann Epidemiol*. 2015. doi:10.1016/j.annepidem.2015.05.007

25. Schmid D, Leitzmann MF. Television viewing and time spent sedentary in relation to cancer risk: a meta-analysis. *J Natl Cancer Inst*. 2014;106(7):pii:dju098.

26. World Cancer Research Fund International. *Continuous Update Project Report: Diet, Nutrition, Physical Activity and Prostate Cancer*. London (UK): World Cancer Research Fund International; 2014.

27. World Cancer Research Fund. *Continuous Update Project Report. Food, Nutrition, Physical Activity, and the Prevention of Endometrial Cancer*. Washington (DC): American Institute for Cancer Research; 2013.

28. World Cancer Research Fund. *Continuous Update Project Report. Food, Nutrition, Physical Activity, and the Prevention of Ovarian Cancer*. Washington (DC): American Institute for Cancer Research; 2014.

29. World Cancer Research Fund. *Continuous Update Project Report. Food, Nutrition, Physical Activity, and the Prevention of Breast Cancer*. Washington (DC): American Institute for Cancer Research; 2010.

30. World Cancer Research Fund. *Continuous Update Project Report. Food, Nutrition, Physical Activity and the Prevention of Colorectal Cancer*. Washington (DC): American Institute for Cancer Research; 2011.

31. World Cancer Research Fund. *Continuous Update Project Summary. Food, Nutrition, Physical Activity, and the Prevention of Pancreatic Cancer*. Washington (DC): American Institute for Cancer Research; 2012.

32. World Cancer Research Fund. *Continuous Update Project Report: Diet, Nutrition, Physical Activity and Liver Cancer*. Washington (DC): American Institute for Cancer Research; 2015.

33. Singh S, Devanna S, Edakkanambeth Varayil J, Murad MH, Iyer PG. Physical activity is associated with reduced risk of esophageal cancer, particularly esophageal adenocarcinoma: A systematic review and meta-analysis. *BMC Gastroenterol*. 2014;14:101.

34. Keimling M, Behrens G, Schmid D, Jochem C, Leitzmann MF. The association between physical activity and bladder cancer: Systematic review and meta-analysis. *Br J Cancer*. 2014;110(7):1862-70.

35. Singh S, Edakkanambeth Varayil J, Devanna S, Murad MH, Iyer PG. Physical activity is associated with reduced risk of gastric cancer: A systematic review and meta-analysis. *Cancer Prev Res (Phila)*. 2014;7(1):12-22.

36. Buffart LM, Singh AS, van Loon EC, Vermeulen HI, Brug J, Chinapaw MJ. Physical activity and the risk of developing lung cancer among smokers: A meta-analysis. *J Sci Med Sport*. 2014;17(1):67-71.

37. Liu Y, Hu F, Li D, Wang F, Zhu L, Chen W, et al. Does physical activity reduce the risk of prostate cancer? A systematic review and meta-analysis. *Eur Urol*. 2011;60(5):1029-44.

38. Behrens G, Jochem C, Schmid D, Keimling M, Ricci C, Leitzmann MF. Physical activity and risk of pancreatic cancer: A systematic review and meta-analysis. *Eur J Epidemiol*. 2015;30(4):279-98.

39. Zaridze DG. Environmental etiology of large-bowel cancer. *J Natl Cancer Inst*. 1983;70(3):389-400.

40. Giovannucci E. Insulin, insulin-like growth factors and colon cancer: A review of the evidence. *J Nutr*. 2001;131 Suppl 11:3109-20.

41. Feskens EJ, Loeber JG, Kromhout D. Diet and physical activity as determinants of hyperinsulinemia: The Zutphen Elderly Study. *Am J Epidemiol*. 1994;140(4):350-60.

42. Kaaks R. Nutrition, insulin, IGF-1 metabolism and cancer risk: A summary of epidemiological evidence. *Novartis Found Symp*. 2004;262:247-60; discussion 260-68.

43. Ahmed RL, Thomas W, Schmitz KH. Interactions between Insulin, Body Fat, and Insulin-Like Growth Factor Axis Proteins. *Cancer Epidemiol Biomarkers Prev*. 2007;16(3):593-7.

44. Tran TT, Medline A, Bruce WR. Insulin promotion of colon tumors in rats. *Cancer Epidemiol Biomarkers Prev*. 1996;5(12):1013-5.

45. Pai R, Nakamura T, Moon WS, Tarnawski AS. Prostaglandins promote colon cancer cell invasion; signaling by cross-talk between two distinct growth factor receptors. *FASEB J*. 2003;17(12):1640-7.

46. Cooper K, Squires H, Carroll C, Papaioannou D, Booth A, Logan RF, et al. Chemoprevention of colorectal cancer: Systematic review and economic evaluation. *Health Technol Assess*. 2010;14(32):1-206.

47. IARC Working Group on the Evaluation of Cancer-Preventive Strategies. Weight Control and Physical Activity. In: Vainio H, Bianchini F, editors. *IARC Handbooks of Cancer Prevention*. Lyon (FRC): IARC Press; 2002. p. 83-199.

48. McTiernan A, Tworoger SS, Rajan KB, Yasui Y, Sorenson B, Ulrich CM, et al. Effect of exercise on serum androgens in postmenopausal women: A 12-month randomized clinical trial. *Cancer Epidemiol Biomarkers Prev*. 2004;13(7):1099-105.

49. Mitsuzono R, Ube M. Effects of endurance training on blood lipid profiles in adolescent female distance runners. *Kurume Med J*. 2006;53(1-2):29-35.

50. Wu F, Ames R, Evans MC, France JT, Reid IR. Determinants of sex hormone-binding globulin in normal postmenopausal women. *Clin Endocrinol (Oxf)*. 2001;54(1):81-7.

51. Kaaks R, Lukanova A, Kurzer MS. Obesity, endogenous hormones, and endometrial cancer risk: A synthetic review. *Cancer Epidemiol Biomarkers Prev*. 2002;11(12):1531-43.

52. Key TJ. Endogenous oestrogens and breast cancer risk in premenopausal and postmenopausal women. *Steroids*. 2011;76(8):812-15.

53. Australian Bureau of Statistics. *4364.0.55.001 – Australian Health Survey: First Results 2011-12*. Canberra (AUST): ABS; 2011.

54. Wong JY, Gilson ND, van Uffelen JG, Brown WJ. The effects of workplace physical activity interventions in men: A systematic review. *Am J Mens Health*. 2012;6(4):303-13.

55. Kahn EB, Ramsey LT, Brownson RC, Heath GW, Howze EH, Powell KE, et al. The effectiveness of interventions to increase physical activity. A systematic review. *Am J Prev Med*. 2002;22 Suppl 4:73-107.

Supporting Information

Additional supporting information may be found in the online version of this article:

Supplementary Table 1: Average minutes spent per week undertaking different levels of exercise, by age and sex (Australia, 2001) amongst people who exercise.

Supplementary Table 2: Formulae used to calculate average total minutes spent in each physical activity category.