Walking time, sports activity, job type, and body posture during work in relation to incident colorectal cancer: the JACC prospective cohort study

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Abstract
Purpose An inverse association between physical activity and colorectal cancer (CRC) has been suggested. We aimed to assess the specific and combined effects of leisure-time and occupational physical activities on CRC risk among Japanese adults.

Methods Using Cox proportional hazard models, we tested whether walking time, sports activity, body posture during work, and job type—or the combination of these variables—were associated with CRC incidence in a prospective cohort of 26,897 Japanese adults aged 40–79 years.

Results During a median 17-year follow-up (1990–2009) period, we ascertained 423 incident cases of CRC (267 colon and 156 rectum cancer). Time spent walking suggested a dose–response inverse relationship with CRC risk (p-trend = 0.051). Manual labor was associated with lower CRC risk when compared to office work with HRs (95% CIs) of 0.74 (0.56–0.97) for CRC and 0.68 (0.48–0.96) for colon cancer. Compared to sitting, moving during work tended to be inversely associated with rectal cancer risk, especially after censoring early incident cases within 3 years after baseline; HR (95% CI) = 0.63 (0.40–0.99). Combining walking and job type suggested mutual and synergistic benefits on the risk of colon cancer (p-interaction = 0.03). Compared to office workers walking < 1 h/day, the HR (95% CI) of colon cancer was 0.48 (0.23–0.98), 0.61 (0.42–0.89), and 0.59 (0.41–0.87) in office workers walking ≥ 1 h/day, non-office workers walking < 1 h/day, and non-office workers walking ≥ 1 h/day, respectively.

Conclusion The time spent walking, job type, and posture during work were independently associated with the reduced incident CRC risk among Japanese men and women.

Keywords Walking time · Sports activity · Job type · Posture during work · Colorectal cancer · Japan

Introduction

In 2020, the International Agency for Research on Cancer ranked colorectal cancer (CRC) the third most commonly diagnosed cancer and the second leading cause of cancer deaths worldwide [1, 2]. In Japan, with the spreading of Westernized lifestyles after World War II, CRC morbidity and mortality were on the rise until the 1990s [3, 4]. However, due to the Japanese recommendation to begin CRC screening at the age of 40—which is very early compared to the recommended screening age of 59 years in the USA or 50–74 years in Europe [2]—, the CRC mortality trend in Japan showed a recent decline [5]. Nonetheless, 10% of Japanese men and 8% of Japanese women are likely to be diagnosed with CRC within their lifetimes [6].
Diet, obesity, and physical activity (PA) were suggested to be major modifiable CRC risk factors [2]. The published literature investigating the relationship between leisure-time [2, 7, 8] or occupational PA [2, 9] and CRC risk reported an inverse association between PA and colon cancer, but not rectal cancer. Several potential mechanisms were proposed to explain these associations, including local gastrointestinal effects, altered immune function, lowered serum cholesterol, and changes in insulin and insulin-like growth factor levels [10].

The World Health Organization recommends adults to practice a moderate-intensity PA for 150 min or a vigorous-intensity PA for 75 min per week [11]. These standards are relatively high to initiate or maintain and accordingly, approximately 50% of East Asians are considered physically inactive [12]. Thus, in this study, we aim to investigate the specific and combined effects of leisure-time PA, posture during work, and job type on the risk of developing CRC among Japanese men and women participating in the Japan Collaborative Cohort (JACC) Study for Evaluation of Cancer Risk.

Materials and methods

JACC study population

Between 1988 and 1990, 110,585 Japanese residents aged 40–79 years from 45 municipalities participated in a nationwide study to establish evidence-based preventive strategies against cancer. Details of the JACC study can be found in previous publications [13, 14]. Data on cancer incidence, job type, and posture during work were unavailable in 21, two, and four study areas, respectively. Among the remaining 56,146 respondents from 22 municipalities, we excluded 11,068 participants with a history of cancer at baseline, 4,302 with missing data on leisure-time PA, and 13,879 with missing data on job type or posture during work. The final sample consisted of 26,897 eligible participants. All respondents consented to participate in this study which was conducted in line with the Declaration of Helsinki and was approved by Osaka University and Hokkaido University's ethical review boards.

Colorectal cancer (CRC)

CRC incident cases were confirmed via population-based cancer registries, major hospital records, and death certificates. The follow-up period ended at the date of death, the date of moving out from the study area, or in December of the following years: 1994 in one study area, 1997 in two areas, 2000 in one area, 2003 in one area, 2006 in two areas, 2008 in three areas, and 2009 for the remaining 12 areas—whichever happened first. Thus, the mean and median follow-up periods were 14.8 and 17.9 years, respectively. The following International Statistical Classification of Diseases and Related Health Problems 10th Revision codes defined CRC: C18–C20 (C180–C189 for colon cancer and C19–C20 for rectal cancer).

Physical activity

In the JACC study, leisure-time PA was assessed with two questions: (1) minutes spent walking per day and (2) hours of sports activity per week. Possible answers on daily walking time were “almost none,” “less than 30 min,” “30 min to less than 1 h,” or “1 h or more.” Responses on weekly sports activity were “almost none,” “1–2 h,” “3–4 h,” or “5 h or more.” The respondents were also asked to specify their job type—“manual work,” “office work,” or “other work”—and their occupational PA level, indicated by their body posture during work—“mainly sitting,” “mainly standing,” “sitting and standing,” or “moving.”

Covariates

The following variables were included in our models as potential confounders: age (continuous), sex (male, female), area of residence, family history of any cancer (yes, no), history of diabetes (yes, no), education (< 15, 16–18, ≥ 19 years), occupation (unemployed, part time, full time, self-employed, housewife, other), hours of TV watching (< 1.5, 1.5 to < 3, 3 to < 4.5, ≥ 4.5 h per day), smoking habit (never, former, current smoker), alcohol consumption (never, former, and current drinker of < 23, 23 to < 46, 46 to < 69, ≥ 69 g of ethanol per day), body mass index calculated as weight in kilograms/squared height in meters (quintiles), as well as total meat, fish, vegetable, dietary fiber, folate, and total calorie intakes (quintiles).

Statistical analyses

Data were analyzed between January and June 2020. Participant characteristics were compared for CRC cases versus non-cases using independent sample t tests and Chi-square tests. Three Cox proportional hazard regression models were constructed to compute hazard ratios (HRs) with 95% confidence intervals (CIs) for developing CRC according to leisure-time PA levels (reference: “almost no” daily walking time/weekly sports activity), job type (reference: “office work”), and posture during work (reference: “mainly sitting”). The first model (Model 1) was adjusted for age, sex, and area of residence. The second model (Model 2) further accounted for all covariates listed above. For the analysis of leisure-time activity, the third model (Model 3) was further adjusted for job type and mutually adjusted for walking and
sports. In contrast, model 3 was further adjusted for walking and sports activities to analyze the association of job type and posture during work with CRC. Sensitivity analyses were conducted after excluding respondents who developed CRC within 3 years of the baseline.

Two- and three-way interaction terms between the exposure variables were added to the models to test their potential synergistic effects on the risk of CRC, colon cancer, and rectal cancer. Multiplicative (synergistic) interaction was considered when a cross-product term of the two or three independent factors was statistically significant. The combined analyses were conducted after creating three new variables, combining (1) walking time and job type, (2) walking time and posture during work, and (3) walking time, job type, and posture during work. The statistical analyses were conducted by SAS 9.4 software (SAS Institute Inc., Cary, 131 NC, USA), and two-sided p-values < 0.05 defined the level of statistical significance.

**Results**

During 397,918 person-years of follow-up, 423 incident CRC cases were diagnosed (398 in men and 125 in women), including 267 cases of colon cancer (175 in men and 92 in women) and 156 cases of rectum cancer (123 in men and 33 in women). Compared to non-cases, the mean age of respondents who developed CRC during the follow-up period was higher at baseline (56.5 vs. 53.0 years). CRC cases were also more likely to be males (70.5% vs. 50.7%), current smokers (37.4% vs. 30.9%), office workers (19.5% vs. 15.7%), and to have higher daily ethanol intake (31.8 vs. 28.8 g/day) and total calorie intakes (1690.2 vs. 1596.4 kcal/day) (Table 1).

Table 2 shows the associations between leisure-time physical activity and incident CRC risk. Daily time spent walking was inversely associated with the risk of CRC in

| Table 1 Characteristics of colorectal cancer cases versus non-cases |
|----------------------------------------------------------|
| All participants of the study                     | Colorectal cancer cases | Non-cases | p for differencea |
| Number of participants                              | 423                     | 26,474    |                |
| Age, year                                           | 56.5 ± 8.2              | 53.0 ± 8.8 | <0.001        |
| Male, %                                             | 70.5                    | 50.7      | <0.001        |
| History of hypertension, %                          | 19.8                    | 15.5      | 0.02          |
| History of diabetes, %                              | 4.9                     | 3.4       | 0.09          |
| Family history of CRC, %                            | 4.3                     | 2.8       | 0.06          |
| Body mass index, kg/m²                               | 22.7 ± 2.7              | 22.8 ± 2.8 | 0.67          |
| Current smoker, %                                    | 37.4                    | 30.9      | <0.001        |
| TV viewing time, hour/day                            | 2.5 ± 1.2               | 2.5 ± 1.3 | 0.92          |
| Education ≥ 16 years, %                              | 66.9                    | 66.8      | 0.98          |
| High perceived stress, %                            | 58.4                    | 59.6      | 0.35          |
| Sports ≥ 3 h/week, %                                 | 11.8                    | 10.2      | 0.28          |
| Walking ≥ 30 min/day, %                              | 68.8                    | 71.1      | 0.29          |
| Job type                                            |                         |           | 0.03          |
| Manual                                              | 43                      | 48.7      |               |
| Office                                              | 19.6                    | 15.7      |               |
| Other                                               | 37.4                    | 36.6      |               |
| Body posture during work                             |                         |           | 0.87          |
| Mostly sitting                                      | 36.6                    | 35.9      |               |
| Sitting/standing                                    | 7.1                     | 6.3       |               |
| Mostly standing                                     | 16.6                    | 17.2      |               |
| Moving                                              | 39.7                    | 40.6      |               |
| Ethanol intake, g/day                               | 31.8 ± 22.4             | 28.8 ± 22.9 | 0.05          |
| Total meat intake, g/day                             | 30.1 ± 19.4             | 30.6 ± 20.3 | 0.64          |
| Fish intake, g/day                                   | 49.3 ± 27.0             | 51.4 ± 27.7 | 0.48          |
| Vegetable intake, g/day                              | 295.9 ± 331.9           | 264.4 ± 316.1 | 0.05          |
| Dietary fiber intake, g/day                          | 10.8 ± 3.3              | 10.3 ± 3.3 | 0.01          |
| Folate intake, mg/day                                | 429.8 ± 164.2           | 416.6 ± 158.8 | 0.13          |
| Energy intake, kcal/day                              | 1,690.2 ± 435.7         | 1,596.4 ± 434.3 | <0.001      |

aIndependent sample t test was used for continuous and Chi-square test for categorical variables
Table 2  Leisure-time physical activity and risk of incident colorectal cancer among Japanese men and women

| Walking | | | | | Sports | | | | |
|---------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|         | Never | < 30 min/day | 30–60 min/day | 1 h or more/day | p-trend | Never | 1–2 h/week | 3–4 h/week | 5 h or more/week | p-trend |
| Participants, n | 3,022 | 4,752 | 5,331 | 13,792 | | 19,677 | 4,462 | 1,508 | 1,250 | |
| Person-year | 42,906 | 69,614 | 78,097 | 207,301 | | 291,231 | 67,027 | 21,677 | 17,982 | |
| Colorectal cancer, n | 49 | 83 | 79 | 212 | | 299 | 74 | 6,831 | 19 | |
| Model 1 | | | | | | | | | | |
| Model 2 | | | | | | | | | | |
| Model 3 | | | | | | | | | | |
| Colon cancer, n | 31 | 47 | 54 | 135 | | 188 | 50 | 16 | 13 | |
| Model 1 | | | | | | | | | | |
| Model 2 | | | | | | | | | | |
| Model 3 | | | | | | | | | | |
| Rectal cancer, n | 18 | 36 | 25 | 77 | | 111 | 24 | 15 | 6 | |
| Model 1 | | | | | | | | | | |
| Model 2 | | | | | | | | | | |
| Model 3 | | | | | | | | | | |

Model 1: adjusted for age, sex, and area of residence
Model 2: further adjusted for body mass index, history of diabetes, family history of cancer, education, occupation, hours of watching TV, smoking habit, ethanol intake, and total meat, fish, vegetable, total dietary fiber, folate, and total energy intakes
Model 3: further adjusted for job type and mutually for walking/sports activity
a dose–response manner. Compared to respondents with almost no walking activity, the multivariable HRs (95% CIs) for CRC risk among participants walking < 30 min/day, 30 min/day to < 1 h/day, and ≥ 1 h/day were 0.92 (0.65–1.31), 0.78 (0.55–1.12), and 0.74 (0.54–1.02), respectively; \( p \)-trend = 0.027 (Model 2). Further adjustment for sports activity and job type attenuated the association; \( p \)-trend = 0.051 (Model 3). The decreasing CRC risk across longer daily walking time categories was observed for colon and rectal cancers; however, these trends did not reach statistical significance. Higher sports activity was not significantly associated with CRC risk. Also, there were no significant interactions between sex and leisure-time physical activities; \( p \)-interaction > 0.1.

The results presented in Table 3 indicate that manual workers were at a lower risk of incident CRC and colon cancer than office workers; the multivariable HR (95% CI) in the fully adjusted model (Model 3) was 0.74 (0.56–0.97) for CRC and 0.68 (0.48–0.96) for colon cancer. The association between higher occupational PA—moving versus sitting during work—and CRC risk was in the same direction. However, it did not reach statistical significance; the multivariable HR (95% CI) was 0.86 (0.67–1.11) for CRC and 0.72 (0.47–1.10) for rectal cancer. The findings did not change substantially after excluding CRC cases diagnosed during the first 3 years of the follow-up period (Online Resources 1 and 2).

We repeated all the analyses using dichotomized job type (office vs. non-office workers) and body posture during work (moving vs. non-moving) categories. Combining the “manual work” and “other work” categories, “non-office workers” showed lower CRC risk than “office workers”; the multivariable HR (95% CI) was 0.74 (0.58–0.97) for CRC and 0.71 (0.52–0.98) for colon cancer. Similarly, moving during work was associated with lower CRC risk than all other body postures—sitting, standing, and sitting/standing—combined; the multivariable HR (95% CI) was 0.86 (0.68–1.03) for CRC and 0.72 (0.50–1.00) for rectal cancer (data not shown).

Table 4 shows the combined impact of walking activity and job type on the one hand and walking activity and body posture during work on the other hand on CRC risk. Compared to office workers walking < 1 h/day, the HR (95% CI) for incident CRC among non-office workers was 0.74 (0.54–1.00) for respondents walking < 1 h/day and 0.67 (0.49–0.91) for respondents walking ≥ 1 h/day (Model 3). Similar associations were observed for incident colon cancer risk; the corresponding HRs (95% CIs) were 0.61 (0.42–0.89) and 0.59 (0.41–0.87), respectively. The \( p \)-value for interaction between walking and job type was 0.53 for CRC, 0.03 for colon cancer, and 0.14 for rectal cancer risk.

Participants with moving posture during work and ≥ 1 h/day walking time had the lowest CRC and rectal cancer risks (reference: sitting, standing, or sitting/standing body posture during work with < 1 h/day walking time); the multivariable HR (95% CI) was 0.72 (0.55–0.95) for CRC and 0.64 (0.41–0.99) for rectal cancer. The \( p \)-value for interaction

| Job type | Office work | Manual work | Other work | Sitting | Standing | Sitting/standing | Moving |
|----------|-------------|-------------|------------|---------|----------|-----------------|--------|
| Participants, \( n \) | 13,079 | 4,234 | 9,584 | 9,674 | 1,686 | 4,621 | 10,916 |
| Person-year | 195,025 | 65,202 | 137,691 | 148,984 | 24,414 | 66,229 | 158,292 |
| Colorectal cancer, \( n \) | 182 | 83 | 158 | 155 | 30 | 70 | 168 |
| Model 1 | 0.70 (0.54–0.91) | 0.77 (0.58–1.03) | 1 | 1.13 (0.76–1.67) | 1.00 (0.74–1.34) | 0.83 (0.64–1.06) |
| Model 2 | 0.72 (0.55–0.95) | 0.80 (0.60–1.07) | 1 | 1.15 (0.78–1.71) | 0.98 (0.73–1.32) | 0.83 (0.65–1.07) |
| Model 3 | 0.74 (0.56–0.97) | 0.83 (0.62–1.11) | 1 | 1.15 (0.78–1.71) | 0.99 (0.74–1.32) | 0.86 (0.67–1.11) |
| Colon cancer, \( n \) | 108 | 53 | 106 | 92 | 16 | 47 | 112 |
| Model 1 | 0.63 (0.45–0.88) | 0.75 (0.52–1.07) | 1 | 1.00 (0.59–1.71) | 1.07 (0.74–1.55) | 0.89 (0.66–1.22) |
| Model 2 | 0.67 (0.47–0.95) | 0.80 (0.55–1.14) | 1 | 1.05 (0.61–1.79) | 1.05 (0.73–1.52) | 0.93 (0.68–1.28) |
| Model 3 | 0.68 (0.48–0.96) | 0.82 (0.57–1.18) | 1 | 1.05 (0.61–1.79) | 1.06 (0.73–1.53) | 0.96 (0.70–1.32) |
| Rectal cancer, \( n \) | 74 | 30 | 52 | 63 | 14 | 23 | 56 |
| Model 1 | 0.83 (0.54–1.28) | 0.81 (0.50–1.30) | 1 | 1.31 (0.73–2.34) | 0.88 (0.54–1.44) | 0.72 (0.48–1.08) |
| Model 2 | 0.82 (0.52–1.28) | 0.80 (0.49–1.31) | 1 | 1.30 (0.72–2.34) | 0.89 (0.54–1.46) | 0.69 (0.46–1.04) |
| Model 3 | 0.86 (0.55–1.37) | 0.85 (0.52–1.37) | 1 | 1.29 (0.71–2.31) | 0.90 (0.54–1.47) | 0.72 (0.47–1.10) |

Model 1: adjusted for age, sex, and area of residence
Model 2: further adjusted for body mass index, history of diabetes, family history of cancer, education, occupation, hours of watching TV, smoking habit, ethanol intake, and total meat, fish, vegetable, total dietary fiber, folate, and total energy intakes
Model 3: further adjusted for leisure-time physical activities (walking and sports activity)
between walking and body posture during work was 0.27 for CRC, 0.18 for colon cancer, and 0.97 for rectal cancer risk.

We created eight cross-matched PA categories combining walking time, job type, and body posture during work (Online Resource 3). Compared to office workers mainly sitting or standing during work and walking < 1 h/day, the HR (95% CI) for colon cancer was 0.61 (0.39–0.97) among non-office workers walking < 1 h/day, 0.42 (0.17–0.98) among office workers walking ≥ 1 h/day, and 0.55 (0.36–0.86) among non-office workers walking ≥ 1 h/day. The p-values for interactions among all possible combinations of walking time, job type, and body posture during work were > 0.01 for all outcomes, except for walking with job type on colon cancer risk (p = 0.03).

### Discussion

This nationally representative longitudinal study found that higher leisure-time and occupational PA were associated with lowered CRC risk among middle-aged and older Japanese. It also added evidence on the potential synergistic effect of job type and daily walking activity in preventing colon cancer and the benefits of a more active working environment for reduced rectal cancer risk.

The findings align with the previously published literature suggesting a positive association between PA and reduced CRC risk, observed in both Japanese [15–17] and non-Japanese populations [18–22]. In a systematic review and meta-analysis of 14 published articles, the pooled relative risk
was 0.93 (0.89–0.98) among men and 0.99 (0.93–1.06) among women, comparing the lowest versus highest categories of leisure-time PA [7]. Another meta-analysis of 21 articles showed a 27% risk reduction of colon cancer among the most versus the least physically active participants [8]. In a Norwegian population-based cohort study, a leisure-time PA level equivalent to ≥ 4 h weakly walking time compared to a sedentary lifestyle was associated with a RR of 0.62 (95% CI 0.40–0.97) for developing colon cancer [23]. The Miyagi cohort study, conducted in the northern region of Japan, found that walking ≥ 1 h/day during the year preceding the baseline survey was associated with 44% and 62% reduced risk of CRC and colon cancer, respectively, after 7 years of follow-up among men; however, this association was not evident among women [16]. The authors attributed the null findings among women to limited statistical power [16] and potential differences in walking pace between men and women [24]. Similarly, in the Japan Public Health Center (JPHC)-based study, the multivariable HR (95% CI) for colon cancer was 0.58 (0.39–0.87) among men and 0.89 (0.54–1.49) among women, comparing the highest metabolic equivalent (MET) hours per day quartile to the lowest [15]. The authors emphasized in their discussion that the observed gender difference could be due to possible misclassifications of PA levels among women whose PA level was mainly attributed to housework, as opposed to the more common occupational PA among men. In our analyses, there was no significant interaction between sex and PA (p > 0.1). However, after stratification by sex, the 95% CIs of the risk estimates became inflated due to the loss of statistical power among women (data not shown).

In the current study, office workers were at a significantly higher risk of incident CRC and colon cancer than non-office workers. Likewise, previous publications found that workers with sedentary jobs showed an increased CRC risk, especially for colon cancer [20–22]. In an extensive study of 1.1 million Swedish men, the RR (90% CI) of colon cancer among men with sedentary work compared to men with more physically demanding occupations was 1.3 (1.2–1.5) after 19 years of follow-up [25]. Similar findings were reported in other Swedish [22], American [26], and Turkish [27] studies.

Body posture during work was suggested to be a proxy measure for occupational PA level [28]. A large census-based Canadian study of 1,108,410 men and 942,905 women (mean age 41.7 and 40.2 years, respectively) found that respondents who mainly sat during work had an increased risk of developing colon cancer compared to those reporting other working body postures. The multivariable HR (95% CI) comparing other body postures to sitting during work was 0.93 (0.89–0.98) among men and 0.99 (0.93–1.06) among women during 17.7 years of follow-up [28]. A meta-analysis of 28 epidemiological studies that identified 46,071 new CRC cases among 7,84,339 participants reported that a 2-h increment in daily occupational sitting time was associated with a 4% higher CRC risk (RR = 1.04 95% CI 1.01–1.08) [9]. In our study, respondents whose work required “moving” tended to have a reduced CRC and rectal cancer risk, especially those who reported a walking time of ≥ 1 h/day.

To our knowledge, this is the first study to examine the combined effects of leisure-time PA, body posture during work, and job type on incident CRC risk in Asia. Our findings suggest a potential synergistic effect between walking time and job type for reduced colon cancer risk and an additive effect of walking time, job type, and body posture during work for reduced CRC and rectal cancer risk. Previously, Thune and Lund in Norway [23] created a total activity scale by summing recreational and occupational physical activities. Implementing the overall PA scale, they observed that the HRs (95% CIs) for colon cancer risk among physically active versus sedentary participants was 0.63 (0.39–1.04; p-trend = 0.04) and 0.66 (0.40–1.10; p-trend = 0.04) among middle-aged and older women and men, respectively. Similarly, Parent et al. in Canada [20] reported an HR of 0.83 (95% CI 0.63–1.09) for colon cancer risk among respondents with high versus low overall PA, including leisure-time and occupational activities. There are several proposed pathways to explain these observed associations. PA was linked to shorter gastrointestinal transit time and lowered amounts of secreted bile acids and prostaglandins, reducing the number of colonic carcinogens and the exposure time of the intestinal cells to these carcinogens [10]. Also, PA was associated with enhanced immune function, reduced bile acid production, modulated gastrointestinal and pancreatic hormone profiles, and lowered circulating insulin and insulin-like growth factor levels, which are potential cell proliferation and tumor growth stimulators [10].

The current study’s strengths include its community-based longitudinal design with large sample size and the extensive examination of leisure-time and occupational PA’s independent and combined effects on incident CRC risk. However, some important limitations should also be noted. Leisure-time and occupational PA were assessed once at baseline; thus, unmeasured changes in PA levels during the follow-up period might have led to misclassification bias. Second, there were no data on the type or intensity of sports. Also, PA measures were self-reported, indicating the possibility of misreporting; however, the validity of self-reported PA was shown to be satisfactory among Japanese [29]. Despite the adjustment for a wide range of factors, including important dietary variables that were commonly neglected in many previous reports, the possibility of residual confounding cannot be eliminated. For example, the baseline of the JACC study was initiated a few years before the Japanese national cancer screening program covered CRC in 1992.
Accordingly, the JACC study does not have data on this CRC screening, including the medical history of polyps or precancerous lesions. However, excluding early-detected CRC cases within 3 years of the baseline did not affect the observed findings as shown in the sensitivity analyses.

**Conclusion**

In this sizeable Japanese cohort study, walking and moving during work were associated with reduced CRC risk, especially rectal cancer. In contrast, office work was associated with increased CRC risk, mainly for colon cancer. Also, combining leisure-time and occupational PA with job type suggested potential synergistic impacts between walking activity and non-office work for reduced colon cancer risk and additional effects of walking activity and moving during work for reduced rectal cancer risk. These findings imply that increasing the daily walking time or changing the body posture (from sitting to moving) of the office and other sedentary workers may reduce the CRC risk in the population.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s10552-021-01542-x.

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**Authors' contributions** ESE designed the research, analyzed the data, and drafted the manuscript; NH reviewed the manuscript; TA and IH designed the research and reviewed the manuscript. All authors have read the journal’s authorship agreement.

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**Data availability** Upon reasonable request of the study’s steering committee.

**Code availability** Not applicable.

**Declarations**

**Conflict of interest** None. All authors have read the journal’s policy on conflicts of interest.

**Consent to participate** Informed consent was obtained from participants/community representatives.

**Consent for publication** Not applicable.

**Ethical approval** The ethical review boards of Osaka University and Hokkaido University have approved this research.

**References**

1. Sung H, Ferlay J, Siegel RL et al (2021) Global Cancer Statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 71(3):209–249. https://doi.org/10.3322/caac.21660
2. World Cancer Research Fund (2018) Diet, nutrition, physical activity, and colorectal cancer. Available at https://www.wcrf.org/wcrf/pdf/2018/ColorectalCancerReport.pdf
3. Koyama Y, Kotake K (1997) Overview of colorectal cancer in Japan: report from the Registry of the Japanese Society for Cancer of the Colon and Rectum. Dis Colon Rectum 40(10 Suppl):S2-9
4. Kotake K, Koyama Y, Nasu J et al (1995) Relation of family history of cancer and environmental factors to the risk of colorectal cancer: a case–control study. Jpn J Clin Oncol 25:195–202
5. Center for Cancer Control and Information Services, National Cancer Center. Cancer information Services (2018) Projected cancer statistics. https://ganjoho.jp/en/public/statistics/short_pred.html. Accessed 24 Aug 2020
6. Tamakoshi A, Nakamura K, Ukawa S et al (2017) Characteristics and prognosis of Japanese colorectal cancer patients: the BioBank Japan Project. J Epidemiol 27(3S):S36–S42. https://doi.org/10.1016/j.jjep.2016.12
7. Harriss DJ, Atkinson G, Batterham A et al (2009) Lifestyle factors and colorectal cancer risk (2): a systematic review and meta-analysis of associations with leisure-time physical activity. Colorectal Dis 11(7):689–701. https://doi.org/10.1111/j.1463-1318.2009.01767.x
8. Boyle T, Keegel T, Bull F, Heyworth J, Fritschi L (2012) Physical activity and risks of proximal and distal colon cancers: a systematic review and meta-analysis. J Natl Cancer Inst 104(20):1548–1561. https://doi.org/10.1093/jnci/djs354
9. Ma P, Yao Y, Sun W, Dai S, Zhou C (2017) Daily sedentary time and its association with risk for colorectal cancer in adults: a dose–response meta-analysis of prospective cohort studies. Medicine (Baltimore) 96(22):e7049. https://doi.org/10.1097/MD.0000000000007049
10. Quadrilatero J, Hoffman-Goetz L (2003) Physical activity and colon cancer: a systematic review of potential mechanisms. J Sports Med Phys Fit 43(2):121–128
11. World Health Organization (2010) Global recommendations on physical activity for health. World Health Organization, Geneva
12. Wen CP, Wai JP, Tsai MK et al (2011) Minimum amount of physical activity for reduced mortality and extended life expectancy: a prospective cohort study. Lancet 378:1244–1253
13. Tamakoshi A, Ozasa K, Fujino Y et al (2013) Cohort profile of the Japan Collaborative Cohort Study at final follow-up. J Epidemiol 23:227–232
14. Sari GN, Eshak ES, Shirai K, Fujino Y, Tamakoshi A, Iso H (2020) Association of job category and occupational activity with breast cancer incidence in Japanese female workers: the JACC study. BMC Public Health 20(1):1106. https://doi.org/10.1186/s12889-020-09134-1
15. Lee KJ, Inoue M, Otani T et al (2007) Physical activity and risk of colorectal cancer in Japanese men and women: the Japan Public Health Center-based prospective study. Cancer Causes Control 18(2):199–209
16. Takahashi H, Kuriyama S, Tsubono Y et al (2007) Time spent walking and risk of colorectal cancer in Japan: the Miyagi Cohort study. Eur J Cancer Prev 16(5):403–408
17. Pham NM, Mizoue T, Tanaka K et al (2012) Physical activity and colorectal cancer risk: an evaluation based on a systematic review of epidemiologic evidence among the Japanese population. Jpn J Clin Oncol 42(1):2–13. https://doi.org/10.1093/jjco/hyr160
18. Morris JS, Bradbury KE, Cross AJ, Gunter MJ, Murphy N (2018) Physical activity, sedentary behaviour and colorectal cancer risk in the UK Biobank. Br J Cancer 118(6):920–929. https://doi.org/10.1038/bjc.2017.496
19. Park SY, Wilkens LR, Haiman CA, Le Marchand L (2019) Physical activity and colorectal cancer risk by sex, race/ethnicity, and subsite: the multiethnic cohort study. Cancer Prev Res (Phila) 12(5):315–326. https://doi.org/10.1158/1940-6207
20. Parent MÉ, Rousseau MC, El-Zein M, Latreille B, Désy M, Siemiatycki J (2011) Occupational and recreational physical activity during adult life and the risk of cancer among men. Cancer Epidemiol 35(2):151–159. https://doi.org/10.1016/j.canep.2010.09.004
21. Fraser G, Pearce N (1993) Occupational physical activity and risk of cancer of the colon and rectum in New Zealand males. Cancer Causes Control 4(1):45–50
22. Moradi T, Gridley G, Björk J et al (2008) Occupational physical activity and risk for cancer of the colon and rectum in Sweden among men and women by anatomic subsite. Eur J Cancer Prev 17(3):201–208. https://doi.org/10.1097/CEJ.0b013e3282b6fd78
23. Thune I, Lund E (1996) Physical activity and risk of colorectal cancer in men and women. Br J Cancer 73(9):1134–1140
24. Himann JE, Cunninham DA, Rechnitzer PA, Paterson DH (1988) Age-related changes in speed walking. Med Sci Sports Exerc 20:161–166
25. Gerhardsson M, Norell SE, Kiviranta H, Pedersen NL, Ahlbom A (1986) Sedentary jobs and colon cancer. Am J Epidemiol 123(5):775–780
26. Garabrant DH, Peters JM, Mack TM, Bernstein L (1984) Job activity and colon cancer risk. Am J Epidemiol 119(6):1005–1014. https://doi.org/10.1093/oxfordjournals.aje.a113805
27. Vetter R, Dosemeci M, Blair A, Wacholder S, Unsai M, Engin K, Fraumeni JF Jr (1992) Occupational physical activity and colon cancer risk in Turkey. Eur J Epidemiol 8(6):845–850
28. Pahwa M, Harris MA, MacLeod J, Tjepkema M, Peters PA, Demers PA (2017) Sedentary work and the risks of colon and rectal cancer by anatomical sub-site in the Canadian census health and environment cohort (CanCHEC). Cancer Epidemiol 49:144–151. https://doi.org/10.1016/j.canep.2017.06.004
29. Tsubono Y, Tsuji I, Fujita K et al (2002) Validation of walking questionnaire for population-based prospective studies in Japan: comparison with pedometer. J Epidemiol 12:305–309. https://doi.org/10.2188/jea.12.305

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