American Journal of
Preventive Medicine

RESEARCH ARTICLE

The Physical Activity Health Paradox in Type 2 Diabetes

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Introduction: The physical activity health paradox refers to the contrasting associations of leisure-time physical activity and occupational physical activity with cardiovascular disease, but whether this applies to Type 2 diabetes risk is unknown. This study aimed to investigate the physical activity health paradox and age-specific Type 2 diabetes.

Methods: Working adults (N=5,866) in Denmark aged 30−60 years enrolled in the Inter99 cohort at baseline in 1999 were followed in a Diabetes Register. Incidence rates of Type 2 diabetes as a function of age, sex, and separate and combined levels of self-reported occupational physical activity and leisure-time physical activity were modeled using Poisson regression, adjusting for relevant covariates in separate analyses (2024).

Results: Moderate/vigorous leisure-time physical activity was associated with lower risk of Type 2 diabetes than light (rate ratio=0.63, 95% CI=0.46, 0.85). Strenuous occupational physical activity was associated with a slightly higher risk of Type 2 diabetes than moderate occupational physical activity, but the association diminished adjusted for covariates (rate ratio=1.12, 95% CI=0.79, 1.58). Sedentary leisure-time physical activity combined with any level of occupational physical activity was associated with higher risk of Type 2 diabetes than light leisure-time physical activity/moderate occupational physical activity combined (e.g., sedentary leisure-time physical activity and demanding occupational physical activity) (rate ratio=1.68, 95% CI=1.14, 2.48). Moderate/vigorous leisure-time physical activity combined with any level of occupational physical activity was associated with lower risk of Type 2 diabetes (e.g., moderate/vigorous leisure-time physical activity and moderate occupational physical activity) (rate ratio=0.6, 95% CI=0.39, 0.92).

Conclusions: Leisure-time physical activity lowered the risk of Type 2 diabetes regardless of the level of occupational physical activity, whereas no similar beneficial effects were found for occupational physical activity level. The differential effects of occupational physical activity and leisure-time physical activity on Type 2 diabetes suggest that the paradox may also exist in Type 2 diabetes.

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0749-3797/$36.00
https://doi.org/10.1016/j.amepre.2024.11.018

INTRODUCTION

The beneficial effects of leisure-time physical activity (LTPA) on Type 2 diabetes (T2DM) risk are well established.[1,2] However, the prevalence of T2DM has more than doubled globally over the past decade, making it a major public health burden and a societal challenge.[3] The WHO states that physical activity (PA) contributes to preventing and managing noncommunicable diseases such as cardiovascular diseases and T2DM.[4] The current WHO PA guidelines do not distinguish which domains (e.g., work or leisure time) the recommended PA takes place.[5] One study from 2020 has suggested that many adults mainly accumulate their PA at work,[6] but the global technological advancements in many jobs have decreased the amount of daily occupational PA (OPA).[7] The reduction in OPA could be a significant factor in the rise in T2DM incidences globally. Although initiatives such as WHO's Every Move Counts campaign[8] convey that PA can take place everywhere, this statement has been questioned. Contrasting health effects between work and LTPA in relation to cardiovascular disease have been shown,[9,10] referred to as the PA health paradox.[11]

Currently, it appears that only 2 studies −one by Biswas et al.[12] (2021) and one by Matthews and colleagues[13] (2024)—have studied the PA health paradox and T2DM. Biswas et al.[12] specifically investigated the separate and combined effects of OPA and LTPA on T2DM incidence but found no significant association between OPA and T2DM incidence. The results indicated that high LTPA was protective for those with lower levels of OPA but not for those with high or strenuous OPA.[12] Conversely, an umbrella review found that high OPA reduced the risk of C-reactive protein, a marker of inflammation known as a pathway to T2DM.[14] A new study from Matthews and colleagues[13] assessed the independent and joint associations of OPA and LTPA with incident diabetes and found the contrasting effects of OPA and LTPA, where the combination of high OPA and low LTPA exhibited the greatest risk of diabetes. The evidence is inconsistent and scarce, and the mechanisms behind the potential PA health paradox in relation to T2DM are not fully understood. This is important because detailed knowledge of potentially opposing effects of OPA and LTPA should optimally be incorporated in future PA guidelines as an important contribution to the global prevention of T2DM. Therefore, in this study, data from the Inter99 cohort and national registers were used to investigate whether there were contrasting health effects of OPA and LTPA by examining their separate and combined effects on age-specific incident T2DM. This study hypothesized that high OPA was associated with an increased risk of incident T2DM, whereas high LTPA reduced the risk.

METHODS

Study Population

A total of 6,784 Danish adults aged between 30 and 60 years living in 11 municipalities in a Copenhagen suburb at baseline in 1999−2001 were enrolled in the population-based inter99 cohort.[15]

Measures

Information about OPA and LTPA was obtained using self-reported questionnaires adapted from Saltin and Grimby[16,17] and previously used in several other studies.[11,18,19] Participants were asked to classify themselves into 1 of 4 groups of OPA, *Which description most precisely covers your pattern of PA at work?* (1) *mainly sedentary work without any physical exertion (sedentary)*, (2) *work that to a large extent is carried out standing or walking but otherwise not physically exerting (moderate)*, (3) *standing or walking work that involves some lifting or carrying (demanding)*, or (4) *heavy or fast and physically exerting work (strenuous)*. For LTPA, participants were asked to classify themselves into 1 of 4 groups: *Which description most precisely covers your leisure time PA?* (1) *read, watch television, or engage in other sedentary activities (sedentary)*; (2) *go for a walk, use your bicycle, or perform light PA (light)*; (3) *are an active athlete or performing heavy gardening, housework and so on. for at least 4 hours per week (moderate)*, or (4) *vigorous training and participation in competitive sports several times a week (vigorous)*. In the analyses, group 3 and 4 were combined because there were very few participants in the vigorous (moderate/vigorous) group. To further understand the effects of specific combinations of OPA and LTPA on T2DM incidence, a joint PA variable with the 12 combinations of the 4 OPA and 3 LTPA categories was derived.

Assessment of T2DM status and date of diagnosis was based on a recently established Danish Diabetes Register (DMreg) covering prevalent and incident diabetes from January 1, 1996, to June 30, 2020. In brief, the DMreg register consisted of comprehensive data from the National Patient Register (diagnosis of diabetes (International Classification of Disease, Eight Revision: 249, 250; ICD-10: E10, E11)),[20] the Medicines Products Register (purchase of any antidiabetic medication [ATC A10XXX]),[21] the National Health Service Registry (use of podiatry treatment for people with diabetes),[22] the Danish Adult Diabetes Database (diagnosis of diabetes),[23] and the Eye Examination Database (Diabase)

(diabetic eye examinations)[24] and is described in detail elsewhere.[25−27]

Participants underwent a physical examination, including waist circumference measured in cm. In addition, they answered a self-report questionnaire, including age, sex,[28] alcohol consumption according to the Danish health authorities (categorized as abstinent, according to recommendations, above recommendations, and high consumptions/alcoholic), and smoking (categorized as no, never smoked; no, but smoked previously; occasionally; and yes, daily); influence at work was assessed by a single item: *What level of influence do you normally have on the organization of your daily work?* (1) *high influence*, (2) *some influence*, (3) *very low influence*, or (4) *no influence*. Data on participants' family income and education were obtained from the Danish educational registers through the unique personal identification number in the Danish civil registration system. Education at baseline examination was obtained from the Danish education registers at Statistics Denmark[29] and categorized into lower secondary and below, upper secondary, and tertiary and above. Family income for the whole Danish population was divided into deciles, and a participant's value thus represents their income level compared with that of the Danish population. Information on paternal and maternal history of diabetes was obtained from baseline questionnaire at examination.

Statistical Analysis

Poisson regression analyses were used to estimate incidence rates of T2DM as a function of age and sex, as well as separate and combined levels of OPA and LTPA. Individuals began their risk time at the study inclusion in 1999−2001 and were followed up until the date of diabetes diagnosis (Type 1 or 2), emigration from Denmark, death, or end of follow-up (June 30, 2020). The presented estimates are incidence rate ratios, reflecting the incidence of T2DM in a specific group relative to the selected reference group of OPA, LTPA, and the combined OPA and LTPA variable, respectively. The group with the largest number of participants was chosen as reference group. Each of the 3 exposures and age-specific incidence rate of T2DM was adjusted for relevant covariates in separate models using a complete case approach. Covariant were selected based on existing literature.[30] Models were adjusted for pertinent covariates in 2 separate models. Model 1 was adjusted for age, sex, and the specific PA exposure. Model 2 was additionally adjusted for education, family income, smoking status, alcohol consumption, and paternal and maternal history of diabetes. For the exposures OPA and combined OPA and LTPA, further adjustments in Model 2 for self-rated work influence were performed. For all models, interactions between sex and the specific PA markers (OPA, LTPA, and OPA/LTPA combined) were tested, separately, as well as age and the specific PA markers, separately.

In sensitivity analysis, additional adjustments were performed for waist circumference at the baseline examination to examine whether the potential associations observed in Model 2 were mediated by concurrent adiposity (Model 3). All statistical analyses were performed in 2024 using the R, Version 4.0.2 (The R foundation for Statistical Computing, Vienna, Austria).[31] All descriptive data are presented as mean (SD) or median (IQR) for continuous variables and percentages for categorical variables.

The Inter99 baseline examination was approved by the Regional Scientific Ethics Committee in Denmark (KA 98 155) and registered with ClinicalTrials.gov (NCT00289237). The participants had provided written informed consent before inclusion. Participants could withdraw from the study at any time. Access to and usage of the register data were approved by the Danish data protection authorities under the Capital Region of Denmark (P-2019-511). The study was conducted according to the Helsinki Declaration, and all participants gave written informed content.

RESULTS

Participants from the inter99 cohort diagnosed with either Type 1 or 2 diabetes in a Danish Diabetes Register[25−27] before baseline examination (n=118; 93 with T2DM and 25 with Type 1 diabetes) were excluded. Furthermore, participants currently not employed (n=575) and with missing data on OPA and LTPA (n=205) were excluded. This resulted in a final study population of 5,886.

Table 1 presents background characteristics of the study population stratified by sex. The total study sample comprised 5,866 participants almost equally distributed across sex with a mean age of 45.1 years for women and 46.0 years for men. The mean BMI was 26.2 kg/m^2, and the waist circumference was 79.8 cm and 92.9 cm for women and men, respectively. The majority of participants had a basic education (30.2%), had never smoked (36.3%), were consuming alcohol below the recommended maximum consumption (74.9%), had no paternal (92.1%) or maternal (93.1%) history of diabetes, and were in the some-influence-on-work category (45.8%).

Descriptive characteristics on PA of the study population stratified by sex are listed in the Appendix Table 1 (available online). The study population was followed for 111,581.9 person years. The median follow-up per

Table 1. Background Characteristics of the Total Study Population Stratified by Sex[a]

Characteristic	Total	Female	Male	*p*-value[b]	Missing, *n*
n	5,886	2,973	2,913		
Age baseline (years)	45.6 (7.7)	45.1 (7.7)	46.0 (7.7)	**<0.001**	0
Education				**<0.001**	41
Lower secondary and below	21.6	23.2	20.0		
Upper secondary	50.5	46.4	54.7		
Tertiary and above	27.9	30.4	25.2		
Family income deciles	8 (6–9)	8 (6–9)	8 (6–9)	**0.017**	268
Smoking				**0.002**	15
Yes, daily	34.3	33.3	35.3		
Occasionally	3.6	3.5	3.6		
No, but smoked previously	25.8	24.5	27.2		
No, never smoked	36.3	38.7	33.9		
Alcohol consumption				**<0.001**	179
Abstinent	9.1	12.7	5.5		
According to recommendations	74.9	75.4	74.3		
Above recommendations	12.2	11.1	13.3		
High consumptions/ alcoholic	3.9	0.8	6.9		
BMI adult (kg/m^2)	26.2 (4.5)	25.7 (4.9)	26.8 (4.0)	**<0.001**	—[c]
Waist circumference (cm)	86.3 (13.1)	79.8 (11.9)	92.9 (10.8)	**<0.001**	10
Paternal history of diabetes				0.520	0
No	92.1	91.9	92.4		
Yes	7.9	8.1	7.6		
Maternal history of diabetes				**0.032**	0
No	93.1	92.4	93.8		
Yes	6.9	7.6	6.2		
Self-rated work influence				**<0.001**	168
Large influence on work	42.9	37.4	48.5		
Some influence on work	45.8	50.7	40.9		
Very little influence on work	9.0	9.9	7.9		
No influence on work	2.3	1.9	2.7		

Note: Boldface indicates statistical significance ($p<0.05$).
[a]Data are mean (SD) and percentage for categorical variables.
[b]Differences between strata were calculated by 1-way ANOVA F-test for continuous variables, Pearson's chi-square test of independence for categorical variables with expected counts >4 in all cells, and Fisher's exact test of independence for categorical variables with expected count in any cell <5.
[c]To avoid the display of microdata, — is inserted where the whole number or percentage needs to be masked.

person (Quantiles 25 and 75) was 20.4 years (19.6 and 20.8). During follow-up, there were 663 (400 males and 263 females) incident cases of T2DM (5.9 per 1,000 person years).

In separate analyses of OPA, T2DM incidence was highest among those with strenuous OPA (Table 2, Model 1, RR=1.4; 95% CI=1.02, 1.93; $p<0.05$) than among those with the reference, moderate OPA. The association attenuated and was no longer statistically significant after adjustment for confounders (Model 2) and in sensitivity analyses (Model 3). None of the other estimates for OPA were statistically significant, but a similar pattern was seen, indicating a higher risk of incident diabetes in those with strenuous and sedentary OPA and a lower risk for those with moderate or demanding OPA (Appendix Figure 1, available online). In addition, the effect of PA on T2DM was found to increase with age.

In separate analyses with LTPA, statistically significant and increasing reductions in the risk of diabetes incidence were seen across categories of increasing levels of LTPA intensity compared with light LTPA (Table 3, Model 1) (Appendix Figure 2, available online). After adjustment for covariates in Model 2, estimates attenuated but remained statistically significant for moderate/vigorous LTPA (RR=0.63; 95% CI=0.46, 0.85; $p<0.05$) but not for sedentary. After additional adjustments for waist circumference (Model 3), the risk of incident T2DM attenuated slightly in the moderate/vigorous category and was no longer statistically significant, whereas sedentary

Table 2. Type 2 Diabetes Incidence as a Function of OPA and Selected Covariates[a]

Measure	Model 1[b]	Model 2[c]	Model 3[d] (sensitivity analysis)
n of analysis	5,886	5,273	5,263
Age (per year)[e]	—	—	—
Sex			
Male	ref	ref	ref
Female	**0.65 (0.55, 0.76) *** **	**0.59 (0.49, 0.70) *** **	1.19 (0.99, 1.43)
OPA[f]			
Moderate	ref	ref	ref
Sedentary	1.12 (0.94, 1.34)	1.08 (0.90, 1.31)	0.95 (0.78, 1.15)
Demanding	1.08 (0.87, 1.34)	0.93 (0.74, 1.18)	0.92 (0.73, 1.16)
Strenuous	**1.40 (1.02, 1.93)***	1.12 (0.79, 1.58)	1.04 (0.74, 1.47)
Self-rated work influence			
Large influence on work		ref	ref
Some influence on work		1.04 (0.87, 1.24)	**1.22 (1.02, 1.47)***
Very little influence on work		**1.32 (1.01, 1.74)***	**1.54 (1.17, 2.03)****
No influence on work		1.37 (0.85, 2.21)	1.39 (0.86, 2.24)
Education			
Upper secondary		ref	ref
Lower secondary and below		1.16 (0.95, 1.40)	1.08 (0.89, 1.31)
Tertiary and above		**0.74 (0.60, 0.92)****	0.89 (0.72, 1.10)
Family income deciles		**0.94 (0.90, 0.98)****	**0.94 (0.90, 0.98)****
Smoking			
No, never smoked		ref	ref
Yes, daily		1.19 (0.97, 1.45)	**1.40 (1.14, 1.72)****
Occasionally		0.70 (0.40, 1.23)	0.70 (0.40, 1.23)
No, but smoked previously		1.16 (0.94, 1.43)	1.13 (0.91, 1.40)
Alcohol			
According to recommendations		ref	ref
Abstinent		**1.80 (1.39, 2.33)*****	**1.65 (1.27, 2.15)*****
Above recommendations		0.96 (0.75, 1.24)	0.95 (0.74, 1.22)
High consumption		**1.43 (1.00, 2.03)***	1.40 (0.98, 1.99)
Paternal history of diabetes			
No		ref	ref
Yes		**2.10 (1.67, 2.64)*****	**2.08 (1.65, 2.62)*****
Maternal history of diabetes			
No		ref	ref
Yes		**1.65 (1.28, 2.13)*****	**1.63 (1.26, 2.10)*****
Waist circumference (cm)			**1.06 (1.05, 1.06)*****

Note: Boldface indicates statistical significance (*p<0.05, **p<0.01, and ***p< 0.001).
[a]Results are presented as incidence rate ratios with 95% CIs throughout.
[b]Model 1: adjusted for age and sex.
[c]Model 2: additionally adjusted for education, family income, smoking status, alcohol consumption, paternal and maternal history of diabetes, and self-rated work influence.
[d]Model 3—sensitivity analysis: additionally adjusted for waist circumference.
[e]Risk estimates are not meaningful because age is specified as second-degree polynomial.
[f]No interactions were found between sex and OPA or between age and OPA.
OPA, occupational physical activity.

LTPA now appeared to reduce the risk of diabetes incidence (RR=0.77; 95% CI=0.6, 1; p<0.05).

In the combined analysis of LTPA and OPA, the diabetes incidence was highest among those with a combination of sedentary LTPA and demanding OPA (Table 4, Model 1) (RR=2.06; 95% CI=1.43, 2.97; p<0.001) or strenuous OPA (RR=1.9; 95% CI=1.08, 3.34; p<0.05) than among the reference group with light LTPA and moderate OPA. In addition, those with sedentary LTPA and moderate or sedentary OPA had an increased risk of incident diabetes compared with the reference group (RR=1.54–1.55). These estimates attenuated but remained statistically significant after adjustment for confounders, except for the category sedentary LTPA

Table 3. Type 2 Diabetes Incidence as a Function of LTPA and Selected Covariates[a]

Measure	Model 1[b]	Model 2[c]	Model 3[d] (sensitivity analysis)
n of analysis	5,886	5,410	5,400
Age (per year)[e]	—	—	—
LTPA[f]			
Light	ref	ref	ref
Sedentary	**1.28 (1.02, 1.61)***	1.22 (0.96, 1.55)	**0.77 (0.60, 1.00)***
Moderate/vigorous	**0.62 (0.46, 0.82)****	**0.63 (0.46, 0.85)****	0.75 (0.55, 1.01)
Sex			
Male	ref	ref	ref
Female	**0.52 (0.43, 0.64)*****	**0.49 (0.39, 0.61)*****	0.96 (0.76, 1.20)
Education			
Upper secondary		ref	ref
Lower secondary and below		1.15 (0.95, 1.40)	1.08 (0.89, 1.32)
Tertiary and above		**0.73 (0.59, 0.90)****	0.86 (0.70, 1.06)
Family income deciles		**0.95 (0.91, 0.98)****	**0.94 (0.90, 0.97)*****
Smoking			
No, never smoked		ref	ref
Yes, daily		1.15 (0.94, 1.40)	**1.40 (1.14, 1.71)****
Occasionally		0.70 (0.40, 1.23)	0.69 (0.39, 1.21)
No, but smoked previously		1.13 (0.91, 1.39)	1.09 (0.88, 1.35)
Alcohol			
According to recommendations		ref	ref
Abstinent		**1.64 (1.28, 2.12)*****	**1.59 (1.23, 2.06)*****
Above recommendations		0.94 (0.73, 1.20)	0.95 (0.74, 1.22)
High consumption		1.31 (0.92, 1.85)	1.28 (0.91, 1.82)
Paternal history of diabetes			
No		ref	ref
Yes		**2.11 (1.69, 2.64)*****	**2.12 (1.69, 2.66)*****
Maternal history of diabetes			
No		ref	ref
Yes		**1.63 (1.26, 2.09)*****	**1.59 (1.24, 2.05)*****
Waist circumference (cm)			**1.06 (1.05, 1.06)*****

Note: Boldface indicates statistical significance (*$p<0.05$, **$p<0.01$, and ***$p<0.001$).
[a]Results are presented as incidence rate ratios with 95% CIs throughout.
[b]Model 1: adjusted for age and sex.
[c]Model 2: additionally adjusted for education, family income, smoking status, alcohol consumption, and paternal and maternal history of diabetes.
[d]Model 3—sensitivity analysis: additionally adjusted for waist circumference.
[e]Risk estimates are not meaningful because age is specified as second-degree polynomial.
[f]An interaction was found between sex and LTPA but not between age and LTPA.
LTPA, leisure-time physical activity.

combined with strenuous OPA, which was no longer statistically significant (Model 2). In the sensitivity analysis (Model 3), all the estimates attenuated further, with CIs overlapping zero. The estimate for the combined category sedentary LTPA and sedentary OPA shifted direction and was now associated with a decreased risk of incident T2DM, although not statistically significant. Estimates for moderate/vigorous LTPA in combination with any OPA level showed a reduced risk of incident diabetes compared with the reference group, and only the estimates for moderate/vigorous LTPA in combination with moderate OPA were statistically significant. However, after adjustment for waist circumference in sensitivity analyses (Table 4, Model 3), this estimate was no longer statistically significant. A similar pattern was found in men and women, and only the absolute diabetes incidence was substantially higher in men (Appendix Figure 3, available online).

There was a significant interaction between LTPA and sex but not between LTPA and age. For OPA as well as the combined OPA and LTPA, no interactions with age and sex, respectively, were found. Thus, a simpler model without interactions was chosen for OPA and the combined OPA and LTPA model, and for LTPA, a model with interactions between LTPA and sex but not age was chosen.

Table 4. Type 2 Diabetes as a Function of OPA and LTPA Combined and Selected Covariates[a]

Measure	Model 1[b]	Model 2[c]	Model 3[d] (sensitivity analysis)
n of analysis	5,886	5,273	5,263
Age (per year)[e]	—	—	—
Sex			
Male	ref	ref	ref
Female	**0.64 (0.54, 0.75)*** **	**0.58 (0.49, 0.69)*** **	1.17 (0.97, 1.41)
Occupational and leisure-time physical activity combined[f]			
Light LTPA and moderate OPA	ref	ref	ref
Sedentary LTPA and Sedentary OPA	**1.55 (1.19, 2.03)** **	**1.39 (1.03, 1.86)***	0.78 (0.57, 1.08)
Sedentary LTPA and moderate OPA	**1.54 (1.17, 2.02)** **	**1.45 (1.09, 1.95)***	1.16 (0.87, 1.57)
Sedentary LTPA and demanding OPA	**2.06 (1.43, 2.97)*** **	**1.68 (1.14, 2.48)** **	1.18 (0.79, 1.75)
Sedentary LTPA and strenuous OPA	**1.90 (1.08, 3.34)***	1.52 (0.84, 2.77)	1.31 (0.72, 2.39)
Light LTPA and sedentary OPA	1.07 (0.85, 1.34)	1.06 (0.83, 1.35)	1.10 (0.86, 1.4)
Light LTPA and demanding OPA	0.96 (0.72, 1.28)	0.85 (0.62, 1.15)	0.83 (0.61, 1.12)
Light LTPA and strenuous OPA	1.48 (0.96, 2.29)	1.17 (0.73, 1.88)	1.00 (0.62, 1.62)
Moderate/vigorous LTPA and sedentary OPA	0.73 (0.46, 1.14)	0.72 (0.43, 1.19)	0.83 (0.50, 1.38)
Moderate/vigorous LTPA and moderate OPA	**0.58 (0.39, 0.86)** **	**0.60 (0.39, 0.92)***	0.78 (0.50, 1.20)
Moderate/vigorous LTPA and demanding OPA	0.80 (0.50, 1.27)	0.73 (0.45, 1.19)	0.94 (0.58, 1.52)
Moderate/vigorous LTPA and strenuous OPA	0.93 (0.46, 1.90)	0.84 (0.41, 1.73)	0.89 (0.44, 1.83)
Self-rated work influence			
Large influence on work		ref	ref
Some influence on work		1.04 (0.87, 1.24)	**1.20 (1.00, 1.44)***
Very little influence on work		1.28 (0.97, 1.69)	**1.50 (1.14, 1.98)** **
No influence on work		1.31 (0.82, 2.11)	1.39 (0.86, 2.24)
Education			
Lower secondary and below		Ref.	ref
Upper secondary		0.88 (0.72, 1.07)	0.93 (0.76, 1.13)
Tertiary and above		**0.66 (0.51, 0.84)*** **	0.83 (0.65, 1.06)
Family income deciles		**0.95 (0.91, 0.98)** **	**0.94 (0.91, 0.98)** **
Smoking			
Yes, daily		ref	ref
Occasionally		0.61 (0.35, 1.07)	**0.48 (0.28, 0.85)***
No, but smoked previously		1.02 (0.84, 1.26)	0.82 (0.66, 1.00)
No, never smoked		0.88 (0.72, 1.07)	**0.73 (0.60, 0.90)** **
Alcohol			
Abstinent		ref	ref
According to recommendations		**0.59 (0.45, 0.76)*** **	**0.61 (0.47, 0.80)*** **
Above recommendations		**0.55 (0.40, 0.77)*** **	**0.58 (0.41, 0.82)** **
High consumption		0.81 (0.53, 1.23)	0.87 (0.57, 1.33)
Paternal history of diabetes			
No		ref	ref
Yes		**2.08 (1.66, 2.62)*** **	**2.04 (1.62, 2.57)*** **
Maternal history of diabetes			
No		ref	ref
Yes		**1.65 (1.28, 2.13)*** **	**1.61 (1.24, 2.08)*** **
Waist circumference (cm)			**1.06 (1.05, 1.06)*** **

Note: Boldface indicates statistical significance (*$p<0.05$, **$p<0.01$, and ***$p< 0.001$).
[a]Results are presented as incidence rate ratios with 95% CIs throughout.
[b]Model 1: adjusted for age and sex.
[c]Model 2: additionally adjusted for education, family income, smoking status, alcohol consumption, paternal and maternal history of diabetes, and for self-rated work influence.
[d]Model 3—sensitivity analysis: additionally adjusted for waist circumference.
[e]Risk estimates are not meaningful because age is specified as second-degree polynomial.
[f]No interactions were found between sex and the combined occupational and LTPA (combined OPA and LTPA) or between age and the combined OPA and LTPA.
LTPA, leisure-time physical activity; OPA, occupational physical activity.

DISCUSSION

In this prospective Danish population-based cohort with almost 2 decades of follow-up time, the results showed that strenuous occupational work could be associated with incident T2DM but not significantly. Conversely, PA during leisure time with moderate/vigorous intensity was associated with a significantly lower risk of T2DM incidence. The results further showed that sedentary leisure time combined with a job that requires any kind of physical occupation was significantly associated with an increased risk of T2DM. Similarly, moderate/vigorous-intensity PA during leisure time combined with any level of occupational PA was protective for incident T2DM.

When studying OPA as a single domain, there was a tendency toward a higher risk of T2DM among those with strenuous OPA compared with those with moderate OPA, although not statistically significant after adjustment for relevant covariates. This has also been shown in other studies.[12,32−36] Nevertheless, OPA up to a certain level may have a beneficial impact on cardiometabolic health. The fact that strenuous OPA was found to increase the risk of incident diabetes supports the hypothesis that although workers engage in strenuous PA at work, this does not improve their cardiometabolic health,[37] a well-known independent predictor for several noncommunicable diseases, for example, diabetes and premature mortality.[38] In addition, workers who are engaged in strenuous PA for a full day of work might suffer from resulting fatigue causing exhaustion after work hours and potentially making them more physically inactive during leisure.[39] Lack of PA after work hours is important because the results showed that PA with moderate/vigorous intensity during leisure time could significantly reduce T2DM incidence across all levels of OPA and after adjusting for potential confounders. Multiple studies support this and highlight the benefits of high PA during leisure.[1,2] The finding in the sensitivity analysis showed that sedentary behavior during work and leisure time became protective for incident T2DM after adjusting for waist circumference (Model 3) but only significant for leisure time sedentary behavior (Table 3). This is likely explained by the effect of sedentary behavior on incident diabetes being mediated through abdominal obesity. This interpretation is supported by previous findings on the effect of sedentary behavior on body weight and body composition.[33,40]

Sedentary behavior during leisure time combined with any kind of PA level during occupation was associated with a significantly higher risk of T2DM than the reference light LTPA combined with moderate OPA. This finding was statistically significant in both unadjusted and adjusted models.

Complementary to these findings, moderate/vigorous LTPA in combination with any level of OPA was associated with lower risk of T2DM, although estimates only reached statistical significance when moderate/vigorous LTPA was combined with moderate OPA. Altogether, these findings highlight the importance of being physically active during leisure time regardless of the level of PA at work. The results support the findings from Biswas et al.[12] (2021) and Matthews and colleagues[13] (2024), where high LTPA in combination with low OPA was found to have a protective effect on T2DM; however, the results were only statistically significant in Matthews et al.[12−14] It is worth noting that there are differences in the measurement of OPA that makes it difficult to compare results directly. Biswas and colleagues[12] used occupational titles on a 5-point scale, whereas Matthews et al.[13] used a dichotomous variable based on a 5-item self-report questionnaire, and this study used self-reported OPA categorized into 4 groups. The fact that Matthews and colleagues[13] used a dichotomized OPA variable may explain the stronger associations between OPA and T2DM found in their study.

Similar to this study, Matthews et al.[13] found an indication of a suggested differing effect of OPA and LTPA on risk of T2DM and thus evidence of the existence of the PA health paradox in relation to T2DM incidence. It is also important to note that when comparing the results of these 3 studies, this study employed light LTPA and moderate OPA as reference groups, whereas the 2 previous studies used the lowest categories of LTPA and OPA as reference groups. The paradox has been shown to apply to other noncommunicable diseases and to all-cause mortality.[9,18,41] However, more evidence, including adjustments for confounders, is needed to further verify these findings.

It is noteworthy that the WHO recommendations on PA do not distinguish between work and leisure time, hence sending a potentially misleading message that daily PA accrued during work hours is sufficient to comply with current activity guidelines. However, the findings along with those of others'[9−11,18,19,41] underscore that leisure time, not occupational moderate/vigorous PA, seems to reduce the risk of incident T2DM, other noncommunicable diseases, and all-cause mortality.

In the sensitivity analysis, no significant results were observed. However, there was an indication of a protective effect of sedentary OPA and LTPA when waist circumference was included as a covariate in sensitivity analyses.

Limitations

Strengths of this study include the large population-based cohort of adults with nearly 20 years register-based follow-up of incident diabetes. However, this

study only accounted for the participants' PA levels during work and leisure time and not whether the person lives a healthy life concerning food consumption. In addition, it should be considered whether strenuous and demanding OPA is mediated through SES because it is often associated with a low SES. In general, a better understanding of confounders and covariates, including SES, health behaviors, and environmental influences, is needed to fully investigate and understand this paradox, and this study cannot exclude the possibility of residual confounding. Likewise, the potential underlying mechanisms behind a possible deleterious effect of strenuous and demanding OPA on T2DM are not fully understood and need further exploration. It has previously been suggested that a potential mechanism may involve low-grade inflammation, for example, C-reactive protein.[14]

This study based the exposures of OPA and LTPA on self-reported surveys collected in 1999–2001, while it was not possible to detect whether the participants had the same job conditions throughout the follow-up period. Self-reported questionnaires have well-known limitations, and this questionnaire is rather crude and may not be exhaustive for respondents to fill in. However, the Saltin and Grimby questionnaires have been found valid and extensively used in several population-based studies.[16] The accuracy of measuring PA could in future studies be supported with device-based measurements from accelerometers.

CONCLUSIONS

In this study, a contrasting effect of OPA and LTPA on the risk of T2DM was found. Whereas LTPA had a marked protective effect on the incidence of T2DM regardless of the level of OPA, no similar beneficial effects were found for OPA level. These findings suggest that the PA health paradox may apply in relation to T2DM incidence. However, more studies are needed to confirm this finding for accumulation of sufficient evidence to inform future recommendations on PA.

ACKNOWLEDGMENTS

Acknowledgments: The authors thank the participants of the Inter99 cohort for their strong commitment to this research. Data supporting the findings of this study are available from Statistics Denmark and the Inter99 database. Restrictions apply to the accessibility of these data, which were analyzed under license for this study.

Disclaimer: The funding sources were not involved in any part of this study and did not influence the decision to submit the paper for publication.

Funding: This work was supported by a research grant from the Danish Diabetes Academy, which is funded by the Novo Nordisk Foundation (Grant Number NNF17SA0031406).

Declaration of interest: RW holds shares in Novo Nordisk A/S. No other disclosures were reported.

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Anna Stage: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. Rasmus Wibaek: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. Pernille F. Rønn: Formal analysis, Writing – review & editing. Kirsten Schroll Bjørnsbo: Resources, Writing – review & editing. Charlotte Brøns: Resources, Writing – review & editing. Karen Allesøe: Conceptualization, Methodology, Investigation, Writing – review & editing. Andreas Holtermann: Conceptualization, Investigation, Writing – review & editing. Allan A. Vaag: Resources, Writing – review & editing. Allan Linneberg: Resources, Writing – review & editing. Mette Aadahl: Conceptualization, Methodology, Investigation, Writing – original draft, Supervision, Project administration, Writing – review & editing.

SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at https://doi.org/10.1016/j.amepre.2024.11.018.

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