The Prospective Association between Physical Activity, and Health-related Quality of Life among Australian Adults Living with Type 2 Diabetes Mellitus

Authors and Affiliation

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Abstract: 260 words

Main manuscript: Around 5,500 words excluding structured abstract, references, tables and figures.

Figures: 5

Tables: 5

Pages: 25 (including abstract and Plain English summary)

Keywords: 4

Appendix: 2

Abbreviations

HILDA	Household, Income and Labour Dynamics in Australia
HRQOL	Health-Related Quality of Life
MCS	Mental Component Summary
PCS	Physical Component Summary
SF-6D	Short-Form Six-Dimension
SF-36	36-Item Short-Form Health Survey
T2DM	Type 2 Diabetes Mellitus
PA	Physical activity

Background

Type 2 diabetes mellitus (T2DM) is a major global public health issue, primarily affecting middle-aged and older adults [1]. The global prevalence of adult diabetes was 10.5% in 2021, accounting for 537 million people living with the disease and associated with US$966 billion direct medical costs in the same year [2]. In Australia, the prevalence of T2DM is high and progressively increasing over the last few decades. The proportion of adult Australians living with T2DM now exceeds 1.3 million people, costing the nation 3.4 billion in 2020-21 [3, 4].

Physical inactivity is an established risk factor for chronic diseases, including T2DM, and a major public health issue [5]. It is associated with increased healthcare costs, reduced productivity, and premature death [4, 5]. For example, globally, it is estimated that physical inactivity will incur an annual cost of approximately US$27 billion [6, 7]. In Australia, 78% of the adult population did not meet the recommended guidelines for physical activity (PA) [8]. It's been evident that chronic diseases and physical inactivity restrict the individual's health and well-being, resulting in worsened general health of people affected, reducing their performance, and Health-Related quality of life (HRQOL) [9, 10]. HRQOL is a valuable tool for evaluating the effects of diseases as well as the effects of treatment interventions. It also provides information about the overall health and well-being of populations that is used for public health planning and policy designs [11].

The health benefit of physical activity is well established and considered "first-line" treatment to help improve clinical risk factors and reduce disease progression in people with and at increased risk of T2DM [12]. Existing literature suggests that increasing physical activity is an effective and preventive strategy to enhance the physical and mental health of people with T2DM [13, 14]. For example, several epidemiologic studies have shown that physical activity is associated with improved physical and mental health, overall HRQOL, and well-being in people with T2DM [15-19]. It has been found that physical activity can lead to better glycaemic control, body composition, blood pressure, insulin resistance, and cognitive performance in people with T2DM, which may contribute to reduced disease complications in these patients [20-22]. Physical activity also has positive effects on mental health, including reducing the risk of depression and anxiety in people with T2DM [23] . Of note, these positive effects of physical activity controlling risk factors for T2DM and reducing mental disorders in people with T2DM could potentially improve their HRQOL.

Such improvements have been reported in systematic reviews and meta-analyses, and randomized controlled trials, which have found that exercise interventions, including aerobic exercise, resistance exercise, combined exercise, and yoga, can improve HRQOL in people with T2DM [13, 18, 24]. Furthermore, meeting weekly physical activity recommendations has been associated with better physical functioning and general health in people with T2DM [25]. On the other hand, the recent systematic review and meta-analysis of randomized controlled trials showed that resistance training had a marginal effect on the physical components of HRQOL and a non-significant effect on the mental components of HRQOL [26]. While evidence from a meta-analysis and RCTs supports the beneficial effects of exercise on HRQOL in people with T2DM [13, 18], such evidence has often been based on individual studies with shorter follow-ups and based on smaller sample sizes. Previous studies included in systematic reviews and meta-analyses have a variety of time frames, common duration includes 3 -6 months but some assessed over 12 months to capture the long-term effects. Research suggests that examining the long-term effects (>12 months) is important for populations like older adults because it helps to understand how consistent engagement in physical activity contributes to improving health outcomes and quality of life over time, mitigating risks associated with aging and chronic diseases [27]. The findings of these systematic reviews and meta-analysis studies are inconclusive. Taking these advantages, there is a need to follow these patients over a longer period to evaluate the long-term effect (> 12 months) of physical activity on their HRQOL using large data from a population-based sample adjusting for a broader range of important confounders. Such population-based longitudinal studies including in Australia have focused on the general population with no overt T2DM [28-33]. Additionally, the recent systematic review and meta-analysis indicate that more randomized controlled trials and longitudinal research are needed in middle-aged and older adults [20].

Although the health benefits of physical activity including prevention and control of chronic diseases such as T2DM are well documented [12-14, 34, 35], the long-term relationship between physical activity and HRQOL among people with T2DM, particularly in middle-aged and older adults who are at high risk of the disease has not adequately been studied. Available evidence overlooked and under-researched the impact of long-term physical activity on HRQOL in the middle-aged and older population with T2DM in the Australian context. This study uses large population-based longitudinal data to investigate the impact of long-term physical activity on HRQOL in middle-aged and older adults with T2DM in Australia.

Methodology

Data source and selected study population

We utilized data from the Household, Income and Labour Dynamics in Australia (HILDA) Survey, a large-scale nationally representative longitudinal study of the Australian population that commenced in 2001. The original HILDA survey sample is representative of the Australian population. Since then, this longitudinal study has collected a range of information on key aspects of life, such as wealth, labour market outcomes, household and family relationships, fertility, health, and education from the same household members. The data has been collected from each state and territory. The survey follows the lives of more than 17,000 Australian adults annually. More comprehensive information about the HILDA survey has been published elsewhere [36]. We analyzed data from four waves—waves 9, 13, 17, and 21, spanning 12 years (2009 to 2021). These waves were selected due to the inclusion of updated information on chronic conditions (including T2DM) and the physical activity status of the study participants. Missing observations on the outcomes (HRQOL) and main exposure (physical activity) were excluded. After adjusting the exclusion criteria, our study established an unbalanced panel with 2,472 person-year observations from 1,270 unique persons. Details on the sample selection technique and handling of missing observations are provided in Figure 1.

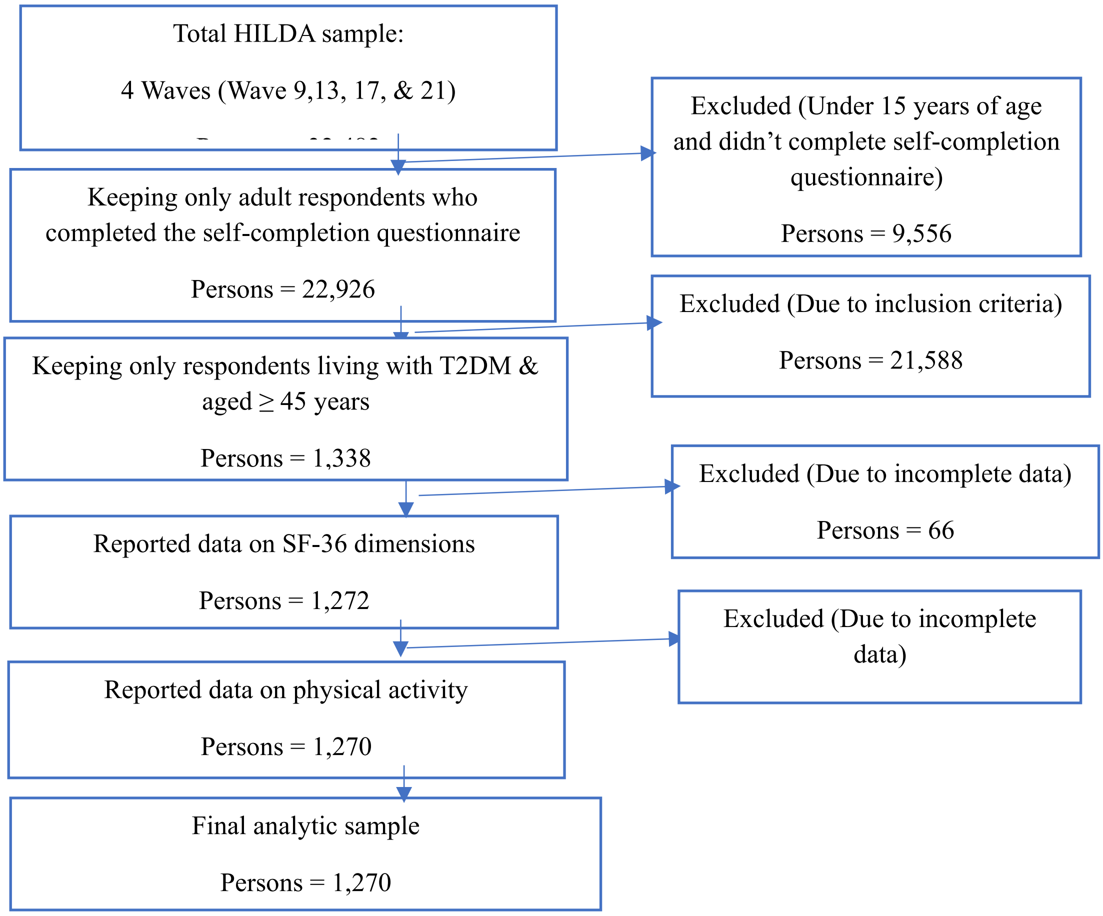

Figure 1: Flow chart showing the selection of HILDA participants for the analyses

Outcome variable

The outcome variable of our study is health-related quality of life (HRQOL). HRQOL of the respondents were assessed through a validated questionnaires, the Short Form Health Survey (SF-36) [37]. It has been validated and used in research to examine the Australian population's health characteristics. Existing evidence suggest that the 8 scales of the SF-36 measure are psychometrically sound, with good internal consistency, discriminant validity, and high reliability [38-40]. The eight domains of HRQOL assessed by the SF-36 instrument include physical functioning (PF), role physical (RP), role emotional (RE), mental health (MH), social functioning (SF), vitality (VT), bodily pain (BP), and general health (GH). The SF-36 has a theoretical range of 0 (representing the worst health) to 100 (representing the best possible health) for each dimension [41]. SF-36 is the most widely used generic profile measure of HRQOL. It evaluates eight health concepts using multi-item scales, consisting of 36 items in total. These concepts include physical functioning (10 items), role limitations caused by physical health problems (4 items), role limitations caused by emotional problems (3 items), social functioning (2 items), emotional well-being (5 items), vitality (4 items), pain (2 items), and general health perceptions (5 items). Additionally, a single item assesses changes in perceived health over the past 12 months. The physical (PCS) and mental (MCS) component summary scales are derived by using a principal components analysis that ensures physical and mental health are not correlated. Both the PCS and MCS are standardized using linear z-score transformations, with a mean of 50 and a standard deviation of 10. The theoretical range for PCS scores is from 4.54 to 76.09, while the range for MCS scores is from -1.21 to 76.19. Higher scores indicate better health states. We also examined the health state utility using the SF-6D, which is a widely recognized method for estimating utilities for profile measures. The SF-6D, also known as the Short-Form Six-Dimension, is a generic preference-based instrument used to measure an individual's HRQOL. It is derived from the SF-36 and utilizes information from six of its subscales: physical functioning, role limitations caused by physical health problems, role limitations caused by emotional problems, social functioning, vitality, and bodily pain. The SF-6D utility value ranges from 0.29 to 1, where 1 represents perfect health and 0.29 represents the worst possible health state [11, 29, 41, 42].

Exposure variable

Physical activity is the primary exposure variable for our study. Data on physical activity was collected by asking the participant, "In general, how often do you participate in moderate or Intensive physical activity for at least 30 minutes? Moderate level physical activity will cause a slight increase in breathing and heart rate, such as brisk walking." Respondents can choose 1 of the following 6 answers: "Not at all," " Less than once a week," "1 or 2 times a week," "3 times a week," "More than 3 times a week (but not every day)," and "Every day" [43]. We used this information to create a variable that captures the frequency of physical activity levels undertaken by survey participants per week. Accordingly, we collapsed the responses into "Not at all", < 1 to 1 or 2 times a week, and 3 times a week to every day.

Potential confounders

Potential confounding factors were selected based on the availability of the variables in the HILDA study and relevant literature [15-17]. The information for potential covariates variables was obtained from the main questionnaire. These factors include age [middle-aged (45-59), older adults (60 and above)], gender (male vs female), origin (Indigenous vs Non-Indigenous), education (year 12 and below, certificate, university degree), labour force status (employed, unemployed/not in the labour force), remoteness area (major city vs regional/remote area), smoking status (never smoked, ex-smoker, & current smoker), alcohol consumption (never drink, ex-drunker, & current drinks), body max index categories (underweight, healthy weight, overweight, & obese), and chronic conditions (no chronic condition, single chronic condition, multi-co-occurring chronic condition). Participants in the HILDA survey were asked whether they had ever been diagnosed with a serious illness or medication condition from the 11 lists including the T2DM that were shown to them. We classify the chronic condition in the same way as in the prior research [41]. We equivalized annual household income using the OECD-modified equivalent scale and then categorized it into quantiles [lowest (poor) to highest (rich)].

Statistical analysis

The data were analyzed using descriptive statistics and longitudinal regression models. Descriptive statistics were used to characterize the analytic sample, such as frequency (percentage) for categorical variables, and mean (standard deviation) for continuous variables. Random-effects GLS (Generalized Least Squares) models were fitted to investigate the relationships between physical activity and HRQOL among people with T2DM middle-aged and older Australians. Controlling for potential confounders, random-effects GLS regression models were used to examine the between-person differences in the association between physical activity and HRQOL. Three separate models were fitted for the component summaries of the SF-36 (PCS, MCS, SF-6D) evaluation of such associations.

We hypothesized that engaging in regular physical activity would positively associate with the HRQOL of middle-aged and older Australians living with T2DM. To examine this hypothesis, we deployed the random-effect GLS models. This model helps to identify the between-person differences in the association between physical activity and HRQOL. The fitted model presented here assumes the following structure:

$$HRQOL_{it} = \alpha_i + \beta_1 PA_{it} + \sum X_{it} + \mu_{it} + \varepsilon_{it}. \qquad \text{(Eq 1)}$$

In Eq 1, $HRQOL_{it}$ stands for i^{th} respondents' health-related summary measures of life quality over the t^{th} time horizon (2009 to 2021). It includes PCS, MCS, and the health utility index (SF-6D). αi (i = 1 to n) refers to the unknown intercept for each entity (n entity-specific intercepts). PA_{it} stands for key variables of interest, where i = entity, t = time, and β1 is the coefficient for the exposure variable. X_{it} demonstrates other confounding factors, μ_{it} refers to between-entity error and ε_{it} indicates within-entity error. The model reported adjusted regression coefficients (βs) with 95% CIs and considered statistical significance at $P < 0.05$. In our study, the main regression results demonstrated the average effects of physical activity on HRQOL, accounting for changes in physical activity over time among adults living with T2DM. We performed a fixed effect panel regression model to check the robustness of our findings. We also performed subgroup analysis stratifying by age and gender. All analyses were performed by STATA 17 version (Stata SE 17, College Station, TX: Stata Corp LLC, USA).

Results

Table 1 shows the characteristics of the final analytic sample ($n_{individuals}$ =1,270; $n_{person\text{-}year\ observation}$=2,472). In the pooled data, more than half (71%) of the study participants were aged greater than 60 years, 45% were female, and 62% were married. Among the study participants, 17% had university degrees, 32% were employed, 60% lived in major cities, 71% were current drinkers, 50% were living with obesity, 63% had a disability, and 53% had multimorbidity. Almost 25% of the participants did not perform physical activity.

Table 1: Socio-demographic and health-related behaviours of study participants

Variables	**Baseline wave (2009)**		**Final wave (2021)**		**All waves Pooled (2009,2013,2017& 2021)**	
	n	**%**	**n**	**%**	**n**	**%**
Age						
45-59	148	34.26	184	25.38	719	29.09
>60	284	65.74	541	74.62	1,753	70.91
Sex						
Male	236	54.63	409	56.41	1,364	55.18
Female	196	45.37	316	43.59	1,108	44.82
Marital status						
Single	164	37.96	280	38.62	948	38.35
Married	268	62.04	445	61.38	1,524	61.65
Race						
Not of Aboriginal/Torres straits	414	95.83	694	95.72	2,360	95.47
islander	18	4.17	31	4.28	112	4.53
Aboriginal/Torres strait islander or both?						
Highest Education level						
attained.	242	56.02	295	40.69	1,179	47.69
Year 12 and below	131	30.32	291	40.14	869	35.15
Certificate	59	13.66	139	19.17	424	17.15
University degree						
Current labour force status						
Employed	139	32.18	238	32.83	794	32.12
Unemployed or NLF	293	67.82	487	67.17	1,678	67.88
Household Income Quintile						
Quantile 1 (poorest)	162	37.50	68	9.38	495	20.02
Quantile 2	69	15.97	139	19.17	494	19.98
Quantile 3	81	18.75	161	22.21	495	20.02
Quantile 4	73	16.90	159	21.93	494	19.98
Quantile 5 (Richest)	47	10.88	198	27.31	494	19.98
Remoteness area						
Major cities	263	60.88	445	61.38	1,480	59.87
Regional/Remote	169	39.12	280	38.62	992	40.13
Smoking						
Never smoker	183	42.36	335	46.21	1,109	44.86
Ex-smoker	188	43.52	325	44.83	1,086	43.93
Current smoker	61	14.12	65	8.97	277	11.21
Alcohol						
Never drink	61	14.12	106	14.62	369	14.93
Ex-drinker	44	10.19	117	16.14	357	14.44
Current drinker	325	75.69	499	69.24	1,746	70.63
Body mass index (BMI)						
Underweight	23	5.32	11	1.52	81	3.28
Healthy weight	53	12.27	104	14.34	321	12.99
Overweight	161	37.27	229	31.59	836	33.82
Obese	195	45.14	381	52.55	1,234	49.91
Disability						
No disability	155	35.88	284	39.17	907	36.69
Has disability	277	64.12	441	60.83	1,565	63.31

Physical activity						
Not at all	105	24.31	189	26.07	619	25.04
<1 to 1-2 times	157	36.34	275	37.93	926	37.46
3 times to everyday	170	39.35	261	36.00	927	37.50
Chronic conditions						
No chronic condition	73	16.90	106	14.62	384	15.53
Single chronic condition	131	30.32	232	32.00	786	31.80
Multiple co-occurring chronic conditions	228	52.78	387	53.38	1,302	52.67

Notes: 1. Abbreviations: ref, reference category; NLF = Not in the labour force 2. In the pooled analysis, a total of 2,472 person-year observations of 1,270 unique persons were included.

Table 2 depicts the distribution of the SF-36 component summary score and dimensions. In the pooled data, the mean score for eight dimensions SF-36 were 62.88 for PF, 52.89 for RP, 70.73 for RE, 71.38 for SF, 72.60 for MH, 52.95 for VT, 56.48 for BP and 52.08 for GH. The mean PCS, MCS, and SF-6D utility values of the respondents were 39.25, 48.16, and 0.69, respectively.

Table 2: Summary statistic of SF-36 component summary and dimensions

Variables	Baseline wave (2009)		Final wave (2021)		Pooled data (wave 9,13,17& 21)	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
SF-36 component summary scores						
Physical component summary	432	39.00 (12.06)	725	39.65 (11.60)	2,472	39.25 (11.92)
Mental component summary	432	48.03 (11.35)	725	48.24 (10.91)	2,472	48.16 (11.29)
SF-6D utility value	432	0.69 (0.13)	725	0.70 (0.13)	2,472	0.69 (0.13)
SF-36 dimensions						
Physical functioning (PF)	432	61.87 (28.89)	725	63.85 (27.98)	2,472	62.88 (28.29)
Role physical (RP)	432	51.85 (43.33)	725	53.72 (44.01)	2,472	52.89 (44.14)
Role emotional (RE)	432	70.21 (41.09)	725	69.88 (41.92)	2,472	70.73 (41.42)
Social functioning (SF)	432	71.03 (29.01)	725	72.81 (27.18)	2,472	71.38 (28.11)
Mental health (MH)	432	72.41 (18.90)	725	72.92 (17.89)	2,472	72.60 (18.61)
Vitality (VT)	432	52.25 (20.25)	725	53.43 (20.69)	2,472	52.95 (21.01)
Bodily pain (BP)	432	56.80 (25.53)	725	57.08 (24.81)	2,472	56.48 (25.66)
General health (GH)	432	51.64 (22.11)	725	52.54 (21.22)	2,472	52.08 (22.01)

Notes: 1. Abbreviations: PCS, Physical Component Summary; MCS, Mental Component Summary; SF6D, Short-Form Six-Dimension health index, PF, physical functioning, RP, Role physical, RE, Role emotional, SF, Social functioning, MH, Mental Health, VT, Vitality, BP, Bodily pain, GH, General Health 2. In the pooled analysis, a total of 2,472 person-year observations of 1,270 unique persons were included.

Figure 2 shows the trend of mean scores of PCS and MCS throughout the study period. The mean PCS and MCS scores showed a distinct trend of increasing and decreasing over time across the studied waves. The mean PCS scores showed clear trends of increasing over the first two waves (2009-2013) and declining from waves (2013-2017) and then starting to rise from this later wave (2021). Similarly, the mean MCS scores showed clear trends of increasing over the first few waves (2009-2013) and declining from waves (2013-2017 and then starting to rise from this later wave. Furthermore, the mean PCS decreased from 48.35 in 20013 to 47.98 in 2017, while the mean MCS declined from 39.36 in 2013 to 38.80 in 2017.

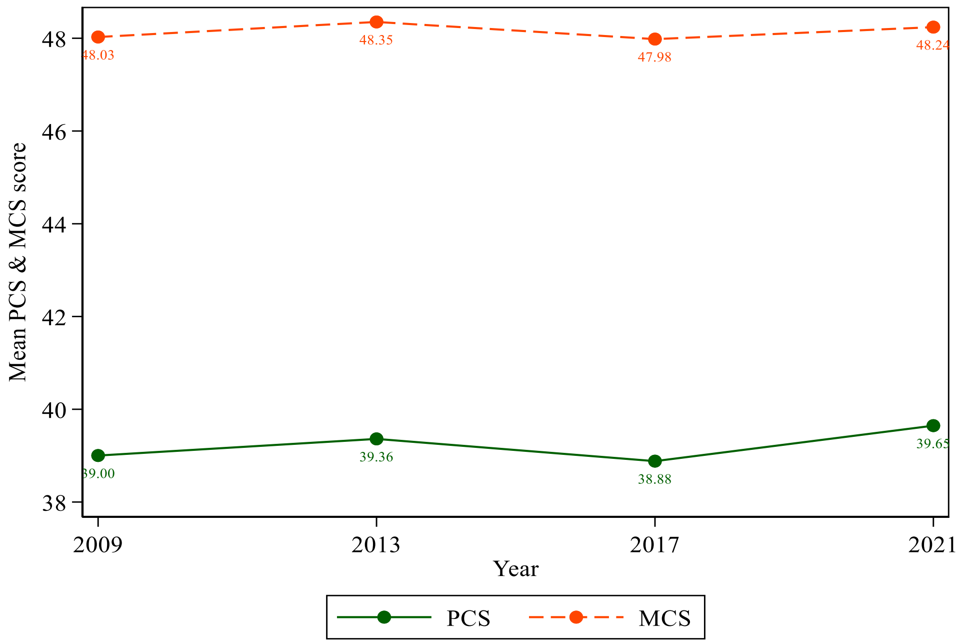

Figure 2: Mean PCS and MCS scores among people living with T2DM over the study period.

Figure 3 displays the mean SF-6D utility value over the study period. The mean SF-6D utility value of Australian adults living with T2DM oscillates between 0.685 to 0.696. Our results show that the mean SF-6D utility value slightly shifted from 0.679 in 2013 to 0.696 in 2017.

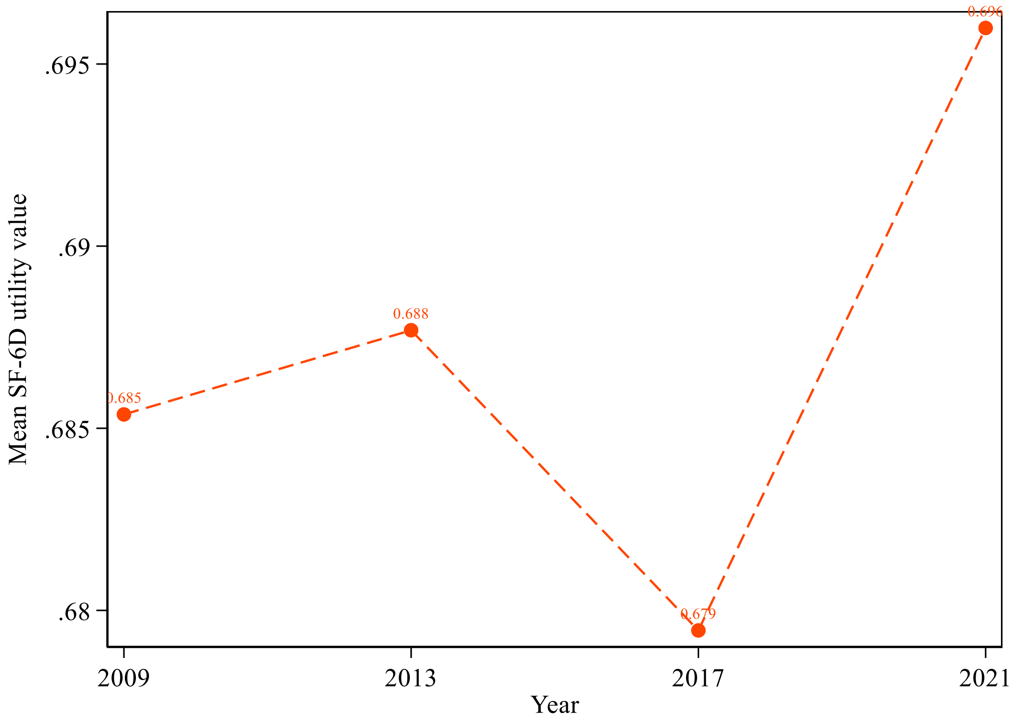

Figure 3: Mean SF-6D utility value among people living with T2DM over the study period.

Figure 4 illustrates the proportion of physical activity in people with T2DM over the study period. The results revealed that over one-fourth of participants with T2DM did not perform physical activity (26.1%) in 2021. The figure also showed that over one-third of the study participants performed physical activity at least 3 times to every day per week (37.9%) in 2021.

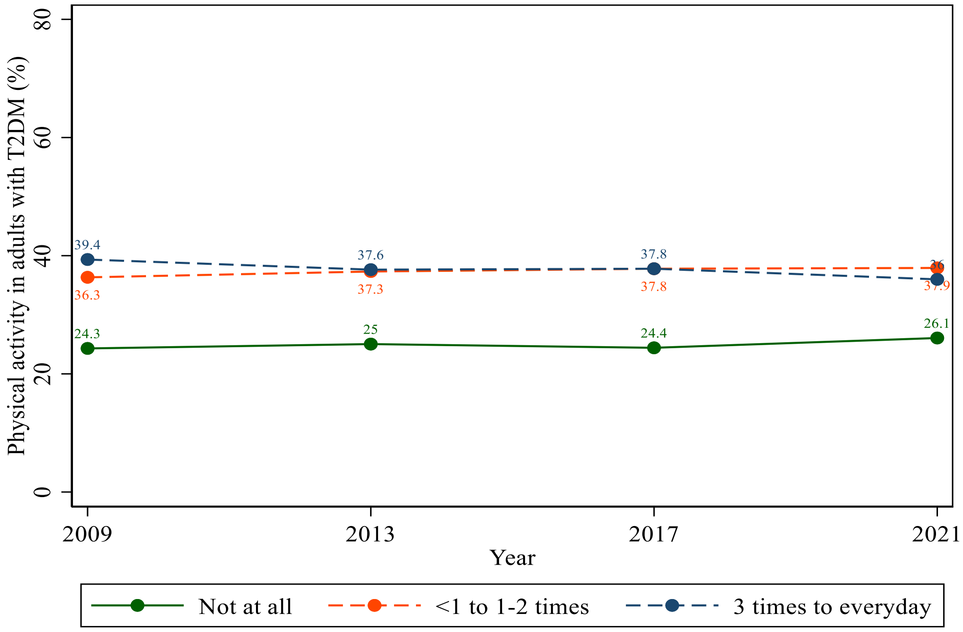

Figure 4: Trend in the proportion of physical activity among people living with T2DM.

Figure 5A presents the mean PCS scores by physical activity over the study period. The figure clearly illustrates that participants who undertook physical activity less than once to 1 or 2 times and 3 times to everyday per week had significantly higher average PCS scores than those who had not engaged in physical activity per week. For example, the mean PCS scores among the participants performing physical activity less than one to 1 or 2 times and 3 times to everyday per week (40.75, and 44.13, respectively) are much higher compared to their counterparts who had not engaged in physical activity per week (31.79%) in wave 21.

Figure 5B also presents the mean MCS, scores by physical activity over the study period. The figure clearly illustrates that participants who undertook physical activity less than once to 1 or 2 times and 3 times to every day per week had significantly higher average MCS scores than those who had not engaged in physical activity per week. For example, the mean MCS scores among the participants performing physical activity less than one to 1 or 2 times and 3 times to everyday (48.34, and 50.70, respectively) are much higher compared to their counterparts who had not engaged in physical activity per week (44.71%) in wave 21.

Additionally, figure 5C presents the mean SF-6D utility value by physical activity across the wave. The figure clearly illustrates that participants who undertook physical activity less than once to 1 or 2 times and 3 times to everyday per week had significantly a higher average SF-6D utility value than those who had not engaged in physical activity per week. For example, the mean SF6D utility value among the participants performing physical activity less than one to 1 or 2 times and 3 times to everyday per week (0.71, and 0.74, respectively) are much higher compared to their counterparts who had not engaged in physical activity per week (0.61) in wave 21.

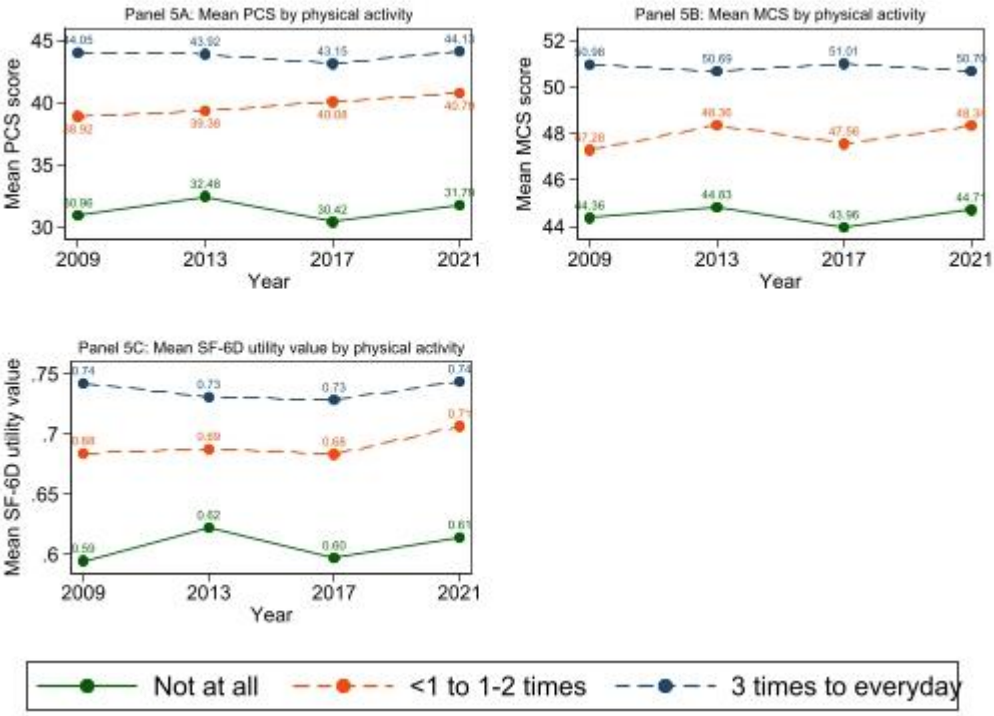

Figure 5: Mean PCS, MCS, and SF-6D utility scores by physical activity among people living with T2DM.

Regression modelling

Table 3 depicts the random-effects GLS estimation of the relationships between physical activity with the SF-36 component summary measures and health state utility value. The estimated coefficient of physical activity regarding the SF-36 summary measures and health utility value was reported in models 1 to 9. All multivariable models show that participants performing physical activity were associated with significantly better HRQOL among people with T2DM and non-T2DM than their counterparts. However, the magnitude is higher for people with T2DM compared to people without T2DM.

Our findings showed that participants with T2DM performing physical activity less than once or 1-2 times per week had higher mean PCS ($\beta = 4.28$, $P < 0.001$), MCS ($\beta = 2.36$, $P < 0.001$), and SF-6D utility value ($\beta = 0.04$, $P < 0.001$) than their counterparts. Similarly, participants with T2DM engaging in physical activity three times every day per week had higher mean PCS ($\beta = 6.65$, $P < 0.001$), MCS ($\beta = 3.75$, $P < 0.001$), and SF-6D ($\beta = 0.07$, $P < 0.001$) than their counterparts (Model 4, 5, and 6 in Table 3). Our result also showed that participants without T2DM performing physical activity less than once or 1-2 times per week had higher mean PCS ($\beta = 3.35$, $P < 0.001$), MCS ($\beta = 1.75$, $P < 0.001$), and SF-6D utility value ($\beta = 0.03$, $P < 0.001$) than their counterparts. Likewise, participants engaging in physical activity three times every day per week had higher mean PCS ($\beta = 4.58$, $P < 0.001$), MCS ($\beta = 3.63$, $P < 0.001$), and SF-6D ($\beta = 0.056$, $P < 0.001$) than their counterparts (Model 1, 2, and 3 in Table 3).

Table 3 also reported the statistically significant association between the interaction of physical activity and T2DM status with component summary measures and SF-6D utility value. The group comparison in the interaction effect showed that people with T2DM engaged in physical activity three times every day per week showed a higher score in PCS ($\beta = 7.04$)

compared to T2DM counterparts who didn't perform physical activity (Model 7). A similar pattern was seen in MCS. T2DM participants engaged in physical activity three times every day per week report 3.65 units higher in MCS scores than their T2DM counterparts who didn't perform physical activity (Model 8). Additionally, the results showed that T2DM participants have higher SF-6D utility values across all physical activity levels. For example, T2DM participants engaged in physical activity three times every day per week have a higher SF-6D utility value (β = 0.07) than T2DM counterparts.

Table 3: A comparative analysis of the association between physical activity and HRQoL among people with and without type 2 diabetes.

Variables	**Australian adults without T2DM**			**Australian adults with T2DM**			**Whole sample**		
	Model 1 PCS β (95% CI), P value	**Model 2 MCS** β (95% CI), P value	**Model 3 SF-6D** β (95% CI), P value	**Model 4 PCS** β (95% CI), P value	**Model 5 MCS** β (95% CI), P value	**Model 6 SF-6D** β (95% CI), P value	**Model 7 PCS** β (95% CI), P value	**Model 8 MCS** β (95% CI), P value	**Model 9 SF-6D** β (95% CI), P value
Physical activity									
Not at all	**Ref**	**Ref**	**Ref**	**Ref**	**Ref**	**Ref**			
<1 to 1-2 times	**3.35 (3.12, 3.57), <0.001**	**1.75 (1.47, 2.03), <0.001**	**0.03 (0.029-0.04), <0.001**	**4.28 (3.38, 5.17), <0.001**	**2.36 (1.38, 3.34), <0.001**	**0.04 (0.03, 0.05), <0.001**			
3 times to everyday	**4.58(4.36, 4.81), <0.001**	**3.63 (3.34, 3.91), <0.01**	**0.056 (0.053, 0.059) <0.001**	**6.65 (5.72, 7.60), <0.001**	**3.75 (2.71, 4.79), <0.001**	**0.07 (0.06, 0.08), <0.001**			
Group comparison in the interaction effects between T2DM and physical activity									
Not at all#No							**3.57 (2.94, 4.21), <0.001**	0 .09 (-0.69, 0.88), 0.804	**0.02 (0.01, 0.03), <0.001**
Not at all#Yes (Ref)							**Ref**	**Ref**	**Ref**
<1 to 1-2 times/week#No							**6.89 (6.27, 7.51), <0.001**	**1.85 (1.08, 2.62), <0.001**	**0.05 (0.04, 0.06), <0.001**
<1 to 1-2 times/week#Yes							**4.57 (3.86, 5.30), <0.001**	**2.07 (1.19, 2.95), <0.001**	**0.04 (0.03, 0.05), <0.001**
3 times to everyday#No							**8.13 (7.51, 8.76), <0.001**	**3.72 (2.95, 4.49), <0.001**	**0 .08 (0.07, 0.09), <0.001**
3 times to everyday#Yes							**7.04 (6.30, 7.79), <0.001**	**3.65 (2.74, 4.56), <0.001**	**0.07 (0.06, 0.08), <0.001**

Notes: 1. Abbreviations: Ref, reference category; PCS, Physical Component Summary; MCS, Mental Component Summary; SF6D, Short-Form Six-Dimension health index. 2. Models (1 to 8) were adjusted for marital status, highest education level completed, household yearly disposable income, labour force status, Indigenous status, region of residence, smoking status, alcohol consumption, body mass index, disability status, and chronic condition. 2. Bold indicates statistically significant (P<0.05).

Subgroup analyses

We conducted the random effects model GLS separately by gender and age to see the heterogeneous effects of physical activity on HRQOL people with T2DM. Our result revealed that participants performing physical activity less than once or 1-2 times and three times to every day per week were positively and significantly associated with PCS, MCS, and SF-6D utility value. Male with T2DM who performed physical activity less than once or 1-2 times per week had higher mean PCS ($\beta = 5.44$, $P < 0.001$), MCS ($\beta = 2.67$, $P < 0.001$), and SF-6D utility value ($\beta = 0.05$, $P < 0.001$) than their counterparts. Likewise, males with T2DM engaged in physical activity three times every day per week had higher mean PCS ($\beta = 7.58$, $P < 0.001$), MCS ($\beta = 4.13$, $P < 0.001$), and SF-6D ($\beta = 0.08$, $P < 0.001$) than their counterparts (Model 1, 2, and 3 in Table 4).

Similarly, our result indicates that females with T2DM engaged in physical activity less than once or 1-2 times was positively associated with PCS ($\beta = 2.93$, $P < 0.001$), MCS ($\beta = 2.05$, $P < 0.001$), and SF-6D utility value ($\beta = 0.03$, $P < 0.001$). Likewise, females with T2DM engaging in physical activity three times every day per week had higher mean PCS ($\beta = 5.39$, $P < 0.001$), MCS ($\beta = 3.29$, $P < 0.001$), and SF-6D ($\beta = 0.06$, $P < 0.001$) than their counterparts (Model 1, 2, and 3 in Table 4). We found similar results for both groups but observed different magnitudes. In general, our findings showed that physical activity had a positive impact on HRQOL for both male and female participants.

Additionally, our results revealed that participants performing physical activity less than once to 1-2 times and three times to every day per week were positively and significantly associated with PCS, MCS, and SF-6D among middle-aged Australians living with T2DM. Similarly, our results revealed that participants performing physical activity less than once to 1-2 times and three times to every day per week were positively and significantly associated with PCS, MCS, and SF-6D among older Australians (aged 60 and above) living with T2DM. We found the same results for both groups, but a different magnitude was observed. For instance, people aged 60 and over who performed physical activity three times to every day per week had significantly improved PCS ($\beta = 6.85$, $P < 0.001$), MCS ($\beta = 3.85$, $P < 0.001$), and SF-6D utility value ($\beta = 0.07$, $P < 0.001$) compared to their counterparts. In general, our findings indicated that physical activity had a positive impact on HRQOL for both those aged between 45 and 59 and those aged 60 and over.

We also examined the effect of physical activity on HRQOL among people aged 15-44 years. Our findings indicate that people with T2DM who engaged in physical activity three to everyday per week showed a significant positive association with PCS exclusively within this age group (Appendix 2).

Table 4: Association between physical activity with the SF-36 component summary scores and SF-6D utility value among people with T2DM stratified by age and gender.

Sub-group		**Model 1 PCS** β (95% CI), P value	**Model 2 MCS** β (95% CI), P value	**Model 3 SF-6D** β (95% CI), P value
Gender				
Male	**Physical activity**			
	Not at all	**Ref.**	**Ref.**	**Ref**
	<1 to 1-2 times	**5.44 (4.25, 6.64), <0.001**	**2.67 (1.36, 3.98), <0.001**	**0.05 (0.04, 0.06), <0.001**

	3 times to everyday	**7.57 (6.34, 8.80), <0.001**	**4.13 (2.76, 5.50), <0.001**	**0.08 (0.06, 0.09), <0.001**
Female	**Physical activity**			
	Not at all	**Ref.**	**Ref.**	**Ref**
	<1 to 1-2 times	**2.93 (1.58, 4.28), <0.001**	**2.05 (0.56, 3.54), 0.007**	**0.03 (0.02, 0.05), <0.001**
	3 times to everyday	**5.37 (3.91, 6.83), <0.001**	**3.29 (1.68, 4.91), <0.001**	**0.06 (0.04, 0.07), <0.001**
Age				
45-59	**Physical activity**			
	Not at all	**Ref.**	**Ref.**	**Ref**
	<1 to 1-2 times	**4.32 (2.55, 6.08), <0.001**	1.73 (-0.36, 3.81), 0.105	**0.04 (0.02, 0.06), <0.001**
	3 times to everyday	**6.45 (4.57, 8.33), <0.001**	**3.12 (0.88, 5.36), 0.006**	**0.06 (0.04, 0.08), <0.001**
60 and above	**Physical activity**			
	Not at all	**Ref.**	**Ref.**	**Ref**
	<1 to 1-2 times	**4.18 (3.12, 5.24), <0.001**	**2.55 (1.41, 3.69), <0.001**	**0.04 (0.03, 0.06), <0.001**
	3 times to everyday	**6.85 (5.76, 7.94), <0.001**	**3.85 (2.68, 5.04), <0.001**	**0.07 (0.06, 0.08), <0.001**

Notes: 1. Abbreviations: Ref, reference category; PCS, Physical Component Summary; MCS, Mental Component Summary; SF6D, Short-Form Six-Dimension health index. 2. Models (1 to 3) were adjusted for marital status, highest education level completed, household yearly disposable income, labour force status, Indigenous status, region of residence, smoking status, alcohol consumption, body mass index, disability status, and chronic condition. 2. Bold indicates statistically significant (P<0.05).

Robustness check

We checked the sensitivity of our main results by fitting our data to the fixed-effects regression model and the results are presented in Table 5. Our results showed that physical activity was positively and significantly associated with PCS, MCS, and SF-6D utility values, which supports what we found using random effects models. Our findings revealed that people with T2DM performing physical activity less than once or 1-2 times and three times to every day per week were positively and significantly associated with PCS, MCS, and SF-6D compared to their counterparts. For example, people with T2DM engaged in physical activity three times to every day per week had a higher mean PCS ($\beta = 4.70$, $P < 0.001$), MCS ($\beta = 2.25$, $P < 0.001$), and SF-6D utility value ($\beta = 0.04$, $P < 0.001$) compared to their counterparts. The consistency of findings demonstrated the robustness of our findings. This finding reconfirms the positive relationship between physical activity and HRQOL among people with T2DM.

Table 5: Results from Fixed-effects GLS models to estimate the association between physical activity with the SF-36 component summary scores and SF-6D utility value among people with T2DM

Variables	**Model 1 PCS** β (95% CI), P value	**Model 2 MCS** β (95% CI), P value	**Model 3 SF-6D** β (95% CI), P value
Physical activity			
Not at all	**Ref**	**Ref**	**Ref**
<1 to 1-2 times	**2.90 (1.73, 4.07), <0.001**	**2.20 (0.99, 3.40), <0.001**	**0.03 (0.02, 0.04), <0.001**
3 times to everyday	**4.70 (3.42, 5.98), <0.001**	**2.25 (0.94, 3.56), 0.001**	**0.04 (0.03, 0.04), <0.001**
Age			
45-59	**Ref**	**Ref**	**Ref**
>60	-0.83 (-2.16, 0.50), 0.220	0.90 (-0.46, 2.26), 0.195	**0.003 (0.006, 0.05), 0.013**
Marital			
Single	**Ref**	**Ref**	**Ref**
Married	**2.82 (0.73, 4.91), 0.008**	**2.47 (0.33, 4.62), 0.024**	**0.03 (0.006, 0.05), 0.013**
Educational status			
Year 12 and below	**Ref**	**Ref**	**Ref**
Certificate III or IV	-0.02 (-7.54, 7.51), 0.997	-4.28 (-11.99, 3.43), 0.276	-0.04 (-0.12, 0.05), 0.402
Undergraduate	11.35 (-5.96, 28.6), 0.198	-4.40 (-22.15, 13.34), 0.626	0.14 (-0.05, 0.34), 0.137

Income			
quantile 1	1.63 (-0.21, 3.48), 0.083	-0.54 (-2.43, 1.37), 0.573	**-0.002 (-0.02, 0.02), 0.865**
quantile 2	1.09 (-0.65, 2.82), 0.218	-.12 (-1.89, 1.66), 0.896	**0.002 (-0.02, 0.02), 0.803**
quantile 3	0.32 (-1.28, 1.91), 0.697	-0.24 (-1.87, 1.39), 0.775	**-0.004 (-0.02, 0.01), 0.672**
quantile 4	0.21 (-1.22, 1.65), 0.769	-0.58 (-2.05, 0.88), 0.435	-0.006 (-0.02, 0.009), 0.426
quantile 5	**Ref**	**Ref**	**Ref**
Labour force			
Employed	**Ref**	**Ref**	**Ref**
Unemployed/NLF	**-3.41 (-4.89, -1.94), 0.001**	-0.44 (-1.96, 1.06), 0.561	**-0.02 (-0.04, -0.003), 0.022**
Remoteness			
Major Cities	**Ref**	**Ref**	**Ref**
Regional/remote	**-2.98 (-5.47, -0.51), 0.018**	1.23 (-1.31, 3.77), 0.343	-0.008 (-0.04, 0.02), 0.565
Smoking			
Never smoked	**Ref**	**Ref**	**Ref**
Ex-smoker	2.08 (-0.59, 4.74), 0.127	2.72 (-0.01, 5.46), 0.051	**0.05 (0.02, 0.08), 0.003**
Current smoker	3.76 (0.28, 7.24), 0.034	**3.61 (0.04, 7.18), 0.047**	**0.05 (0.01, 0.09), 0.012**
Alcohol			
Never drink	**Ref**	**Ref**	**Ref**
Ex drinker	-0.75 (-3.12, 1.62), 0.536	0.47 (-1.96, 2.89), 0.706	-0.002 (-0.03, 0.02), 0.890
Current drinker	0.24 (-2.06, 2.56), 0.837	1.41 (-0.97, 3.78), 0.246	0.007 (-0.02, 0.03), 0.579
Body mass index (BMI)			
Underweight		**Ref**	**Ref**
Healthy weight	-0.43 (-3.43, 2.56), 0.776	-3.29 (-6.37, -0.23), 0.035	-0.01 (-0.05, 0.02), 0.476
Overweight	0.32 (-2.45, 3.09), 0.822	-1.25 (-4.09, 1.58), 0.387	-0.0009 (-0.03, 0.03), 0.950
Obesity	0.46 (-2.36, 3.23), 0.759	-1.23 (-4.09, 1.63), 0.399	-0.002 (-0.03, 0.029), 0.896
Disability			
No disability	**Ref**	**Ref**	**Ref**
Has disability	**-3.50 (-4.58, -2.42), <0.001**	**-0.82 (-1.92, 0.29), 0.146**	**-0.03 (-0.05, -0.02), <0.001**
Chronic condition			
No chronic condition	**Ref**	**Ref**	**Ref**
Single chronic condition	-1.68 (-3.19, -0.17), 0.029	**-1.96 (-3.51, -0.41), 0.013**	**-0.02 (-0.04, -0.007), 0.006**
Multi cooccurring chronic condition	**-3.62 (-5.29, -1.94), <0.001**	**-2.99 (-4.71, -1.28), 0.001**	**-0.05 (-0.07, -0.03), <0.001**

Notes: 1. Abbreviations: ref, reference category; PCS, Physical Component Summary; MCS, Mental Component Summary; SF6D, Short-Form Six-Dimension health index. 2. Bold indicates statistically significant (P<0.05)

Discussion

Engaging in regular physical activity plays a significant role in improving cardiovascular fitness, reducing the risk of chronic disease, and enhancing physical and mental health [7]. Therefore, it is crucial to examine the association between physical activity and quality of life. This study aimed to investigate the role of physical activity on HRQOL among people with T2DM using longitudinal data in Australia. We used the random effect GLS Model to investigate the impact of physical activity on HRQOL among people with T2DM. Our study revealed that physical activity is positively associated with HRQOL. Specifically, people with T2DM performing physical activity less than once or 1-2 times and three times to every day per week had pronounced improved HRQOL than those who did not engage in physical activity. The association is persistent even after controlling for potential confounding variables. In general, our result confirmed our hypothesis that engaging in any physical activity significantly improved the HRQOL among people with T2DM. Our study contributed to the available body of literature by considering the association between physical activity and HRQOL among people with T2DM using nationally representative longitudinal data and random effects GLS regression models. Our study also demonstrates the differential impacts of physical activity on HRQOL among participants with T2DM and without T2DM

Our study results showed that participants performing physical activity less than once or 1-2 times and three times to every day per week had a higher mean PCS than those who had not engaged in physical activity over time. Similarly, participants performing physical activity less than once or 1-2 times and three times to every day per week were positively and significantly associated with PCS among people with T2DM. Our finding is consistent with previous cross-sectional and longitudinal studies focused on T2DM [16, 17, 24, 25]. An explanation for this could be that engaging in regular physical activity has physical benefits (reduced i.e. risk of illness, improved fitness level) [35]. However, the recent findings from a systematic review and meta-analysis are inconsistent with this. They show that resistance training had a non-significant effect on physical component scores [44]. This discrepancy might be explained by the characteristics of the studies included in the review, such as population, sample size, location and in-patient participants with mobility comorbidities, as well as infrequent resistance training (e.g., once a week) [45].

Our result revealed that people with T2DM performing physical activity less than once or 1-2 times and three times to every day per week had higher MCS than those who did not engage in physical activity over time. Our result supported the findings from a previous study conducted among people with T2DM [16, 19, 25]. Our study suggests that undertaking any level of physical activity has psychological benefits (e.g. mental stimulation during participation, and improved psychological health) [35]. In contrast, findings from a meta-analysis of randomized controlled trials did not demonstrate a significant association between resistance exercise and mental aspects [26]. Similarly, a systematic review reported resistance exercise in participants aged 60 years or older failed to improve vitality, and total score for quality of life [44]. This outcome may be attributed to the characteristics of the studies included in the review, which involved in-patient participants with comorbidities to their mobility, as well as low frequency of resistance training (e.g. once weekly) [45].

We found that people with T2DM performing physical activity less than once or 1-2 times and three times to every day per week had greater mean SF-6D utility values than their T2DM counterparts not performing physical activity at all over time. This finding is persistent across gender and age groups. People with T2DM performing physical activity less than once or 1-2 times and three times to every day per week was positively and significantly associated with SF-6D utility value. Our findings corroborated with the previous cross-sectional and longitudinal study focused on a healthy adult population and T2DM [19, 29, 32]. Our result implies that engaging in regular physical activity could reduce the economic and health burdens caused by T2DM [46].

The relationship between physical activity and HRQOL has been found statistically significant in both models we used, which strongly supports the hypothesis that physical activity is associated with greater HRQOL. Our findings showed that as the number of physical activities increased, the value associated with the estimated coefficient for HRQOL also increased. In other words, the higher the level of physical activity, the greater the improvement in HRQOL. These findings are supported by previous studies [28, 29, 31, 47]. However, one study focused only on older women [28], while other studies were cross-sectional and focused on general populations [29, 31].

We also compared the impact of physical activity on HRQOL among people with and without T2DM and T2DM. The findings indicated that each level of physical activity is associated with improved PCS, MCS and SF-6D for both groups, with more pronounced health benefits has been observed in people with T2DM. Additionally, in terms of interaction effects, results highlight that people with T2DM performing any level of physical activity are associated with greater HRQOL compared to their counterparts who do not perform any physical activity. These findings align with prior research indicating that physical activity improves PCS, MCS and SF-6D [28, 29, 47, 48]. Overall, our study suggests that while physical activity is beneficial both for T2DM and non-T2DM participants, tailored intervention might be necessary to optimize the HRQOL for T2DM participants.

Implication for public health policy and practice

Our study found a positive and strong association between physical activity and HRQOL among people with T2DM. Our findings imply the importance of promoting physical activity as a public health initiative and non-pharmacological intervention to improve the quality of life among persons with T2DM. The promotion of physical activity has also the potential to reduce the healthcare cost associated with treating T2DM. The policymakers need to emphasize public health initiatives and healthcare interventions that will increase participation in physical activities among people with T2DM and components of diabetes care [12]. These intervention programs should be targeted at raising awareness of the potential benefit of physical activity for T2DM as ultimately leads to better quality of life. Allocation of resources to community programs is required to support active lifestyles for people with T2DM to improve their overall health outcomes. Healthcare providers should integrate physical activity guidelines into clinical practice and care plans for people with T2DM to enhance their well-being and quality of life. Finally, promoting any form of physical activity among participants with T2DM across both sexes and age groups is essential, given its positive impact on HRQOL and SF-6D utility values. This could be achieved by integrating physical activity programs in community health initiatives, healthcare settings, and preventive education to enhance overall well-being and disease management. Our study has implications for international audiences. The study's findings can guide public health interventions on a global scale, as the benefits of physical activity on quality of life might be universally applicable for middle-aged and older adults with chronic diseases. Local governments and international health organizations can implement similar physical activity programs tailored to specific cultural and infrastructural contexts. By highlighting the role of physical activity in improving HRQOL in people with chronic diseases, the study aligns with the World Health Organization's global action plan on physical activity. This insight can influence policy decisions worldwide, helping nations improve public health outcomes, especially in aging populations living with chronic diseases, and reduce healthcare costs [1, 12, 49].

Strengths, limitations, and avenue for future research

Our study's strengths include the use of a large, nationally representative sample and the utilization of random effects GLS to control potential confounding factors, including chronic conditions, to identify the between person-differences in the relationships between physical activity and HRQOL. The use of a validated HRQOL tool (SF-36 instrument) to ensure the reliability of our findings. However, our study has several limitations that should be acknowledged. First, the inability of the HILDA Survey's physical activity frequency measure to precisely capture individuals' minutes spent on such activities, thus hindering the calculation of metabolic equivalents and precise dose-response patterns for analyzed outcomes [29]. Secondly, reliance on self-reported measures for physical activities, T2DM, HRQOL and other covariates may introduce socially desirable and recall bias. Thirdly, our study was conducted only in Australia. Therefore, the findings may not apply to other populations or cultural contexts. Fourthly, the HILDA data did not include the duration of the type two diabetes exposure, so we couldn't include this variable in our main analysis. Our study has an avenue for future research, the future study should investigate the dose-response relationship between physical activity and HRQOL among people with T2DM. Future studies can explore the economic implications of physical activity, including healthcare costs, work productivity, and overall economic burdens on health service utilization among people with T2DM. Such research holds the potential to provide crucial insight for policymakers and healthcare providers, guiding strategies and investments in physical activity initiatives.

Conclusion

Our study provided robust evidence on the relationship between physical activity and HRQOL among adults living with T2DM using longitudinal data. Our study revealed that engaging in physical activity at least once per week strongly and significantly improved the HRQOL among adults living with T2DM. Given the evidence, our study suggested that there is a need for health education and promotion programs and healthcare intervention across both sexes and across age groups to promote physical activity as a key component of comprehensive approaches to enhance quality of life among people with T2DM. This could help to increase engagement in physical activity and consequently improve the health outcomes of people with T2DM. Moreover, the SF-6D utility value for physical activity obtained from our study could serve as a crucial input in economic evaluation for future studies.

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Declarations

Authors' contribution

Conceptualization: ASB, HSR, TWU, SAK, Formal analysis: ASB, SAK, Methodology: ASB, HSR, TWU, SAK, Writing—original draft: ASB, Writing—review & editing: ASB, HSR, TWU, SAK.

Acknowledgments

The authors are grateful to the Melbourne Institute of Applied Economic and Social Research for providing HILDA data access for conducting the study. This paper uses unit record data from the HILDA Survey guided by the Australian Government's DSS. The findings and views reported in this paper are those of the authors and should not be attributed to the Australian Government, DSS or any contractors or partners of DSS. DOI: 10.26193/OFRKRH, ADA Dataverse, V2.

Ethics Approval

We used secondary data from de-identified existing unit records from the HILDA Survey, so ethical approval was not required. However, the authors completed and signed the Confidentiality Deed Poll and sent it to NCLD (ncldresearch@dss.gov.au) and ADA (ada@anu.edu.au) before receiving approval for their data application. The datasets analyzed and/or generated during the current study are subject to the signed confidentiality deed.

Availability of Data and Materials

The data were obtained from the Melbourne Institute of Applied Economic and Social Research (https://melbourneinstitute.unimelb.edu.au/). Though the information is not openly available, appropriately qualified researchers can access the data after following their protocols and meeting their requirements. Their contact address is Melbourne Institute of Applied Economic and Social Research, the University of Melbourne, VIC 3010, Australia.

Conflict of Interest

The authors have no conflicts of interest to declare.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.