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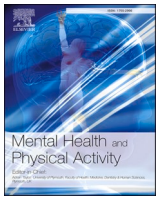

Examining the longitudinal effect of depressive symptoms on physical activity in persons with type 2 diabetes during the COVID-19 pandemic

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A B S T R A C T

Background and aims: The American Diabetes Association recommends that individuals with type 2 diabetes (T2D) engage in at least 150 min of physical activity per week for optimal health. However, depressive symptoms, prevalent in this population, may hinder the ability to follow this recommendation, particularly during stressful events like the COVID-19 pandemic. This longitudinal study aimed at investigating the impact of depressive symptoms on physical activity levels among individuals with T2D during the COVID-19 pandemic.

Methods: We analyzed data from 5348 individuals with T2D participating in the All of Us Research Program's COVID-19 Participant Experience (COPE) survey. Depressive symptoms and physical activity levels were measured using the Patient Health Questionnaire (PHQ-9) and the International Physical Activity Questionnaire (IPAQ), respectively. Stabilized inverse probability weights (sIPW)-weighted mixed-effect logistic regression models evaluated the association between depressive symptoms and physical activity across three time points: May, June, and July 2020.

Results: Participants had a mean age of 61.43 (11.63) years, with majority being female (56.49%) and non-Hispanic White (76.25%). At baseline, 50% of the participants had moderate-to-severe depressive symptoms, and 20% were physically active. The predicted probability of being physically active decreased with increasing depressive symptoms (aOR = 0.66; 95%CI: 0.60, 0.73). The inverse association between depressive symptoms and physical activity was strongest among non-Hispanic White.

Conclusions: Depressive symptoms were significantly associated with lower odds of engaging in physical activity among individuals with T2D during the COVID-19 period. Further studies capturing pre- and post-pandemic data are needed to clarify the pandemic's impact on these associations.

1. Introduction

The global prevalence of diabetes has been on a steady rise, with more than 537 million adults (representing 10.5%) living with the condition as of 2021 (IDF, 2021). In the United States (US), over 11.6% of adults were affected by diabetes in the same year (CDC, 2022), with type 2 diabetes (T2D) being the most prevalent form, accounting for 90–95% of diagnosed cases (CDC, 2020). T2D presents numerous challenges for affected individuals, impacting not only their physical health but also their psychological well-being, which is often overlooked (Akyirem et al., 2022). A recent study revealed that approximately three in five adults with T2D experience mental health difficulties, such as diabetes-related distress, anxiety, and depression (Kelly et al., 2024).

Depression, in particular, disproportionately affects individuals with T2D, who have a two to threefold higher risk of developing the condition compared to the general population (Bădescu et al., 2016). This comorbidity contributes to poorer health outcomes, including worse glycemic control (Ali et al., 2023) and increased risk of diabetes-related complications (Wu et al., 2020). Additionally, several studies highlight the synergistic relationship between depression and diabetes, which significantly reduces quality of life (Juárez-Rojop et al., 2018), increases the risk of disability (Black et al., 2003) and all-cause mortality rate (van Dooren et al., 2013). The impact of depression on health outcomes have been largely linked to its influence on diabetes self-management, with studies indicating a significant association between depression and non-adherence to anti-diabetes medications and healthy eating (Katon et al., 2009; Pouwer et al., 2013; Schmitt et al., 2021). Additionally, several cross-sectional studies have identified an association between

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depression and low uptake of physical activities in individuals with diabetes (Lysy et al., 2008; Mendes et al., 2019).

Physical activity plays a crucial role in the management of T2D. Engaging in regular physical activity has been shown to improve insulin sensitivity, promote weight management, and reduce the risk of cardiovascular complications associated with T2D (Colberg et al., 2016; Cannata et al., 2020). Thus, the American Diabetes Association recommends at least 150 min per week of moderate-intensity aerobic exercise along with at least 2 sessions/week of resistance exercise for individuals with diabetes (Colberg et al., 2016). However, it is likely that individuals with comorbid depression and T2D may not achieve this recommendation as studies have shown that depression can lead to decreased motivation, self-esteem, and increased fatigue, which may diminish interest in physical activities (Sowislo & Orth, 2013; Kraft et al., 2023).

The COVID-19 pandemic introduced additional challenges for individuals with T2D. During the pandemic, people with diabetes were identified as being at increased risk for COVID-19-related hospitalization, intensive care unit admission, and mortality (Kastora et al., 2022; Ekpor & Akyirem, 2023), leading to strong recommendations to adhere to social distancing and lockdown policies. Research suggests that these restrictions exacerbated mental health issues, including depression, while limiting opportunities for physical activity (Leite et al., 2022). For individuals already managing the dual burden of depression and T2D, the barriers to maintaining recommended physical activity levels may have been further intensified during the pandemic.

Whereas several studies have reported a significant association between depression and physical activity, they are predominantly cross-sectional (Lysy et al., 2008; Sumlin et al., 2014; Mendes et al., 2019; Lai et al., 2022), and thus, limits the causal interpretation or directionality of this relationship. The few existing longitudinal studies, were however conducted before the occurrence of the COVID-19 outbreak (Gonzalez et al., 2008; Ivanova et al., 2017), undermining the understanding of the actual impact of depression on physical activity in individuals with T2D during the pandemic period. By prospectively tracking changes in depressive symptoms and physical activity levels over time, the purpose of this study was to investigate the impact of depressive symptoms on physical activity among individuals with T2D during the COVID-19 pandemic. We hypothesized that higher levels of depressive symptoms will be associated with lower levels of physical activity over time.

2. Methods

2.1. The All of Us Research Program

This study uses data from the *All of Us* Research Program. The protocol for this research program has been described elsewhere and has been approved by the program's Institutional Review Board (IRB) (All of Us Research Program Investigators et al., 2019). Briefly, the *All of Us* program is an ongoing National Institute of Health (NIH)-funded longitudinal study that began enrolment of participants in May 2018. The program seeks to recruit more than 1 million adults with a special focus on individuals that are historically underrepresented in medical research in the United States, including racial and sexual minority groups (Ramirez et al., 2022). Enrollment onto this research program occurs online via an app or the program's website. After providing informed consent to the study, participants are asked to complete a battery of questionnaires at baseline. Participants may also consent to sharing their electronic health information and Fitbit data to the study. Further data collection including physical assessments and specimen collection may happen in person at a designated healthcare facility including the over 380 partner healthcare sites (Ramirez et al., 2022).

2.2. COVID-19 Participant Experience survey (COPE)

The COVID-19 Participant Experience (COPE) survey was administered as part of the *All of Us* Research Program at 6 timepoints in May 2020, June 2020, July 2020, November 2020, December 2020, and February 2021 to evaluate the longitudinal impact of the COVID-19 pandemic on health outcomes. The survey contained measures for anxiety, depressive symptoms, physical activity, social support, loneliness, as well as specific COVID-19 questions. The All of Us program provides an opportunity to link participants' responses to the COPE survey to their electronic health records, Fitbit data, genomic data, physical measurements, and other surveys administered as part of the program. For the present study, we conducted a longitudinal analysis of the May, June, and July 2020 COPE surveys. We chose these three surveys because they collected data on physical activity and depressive symptoms using the same instruments.

2.3. Selection of study cohort

Participants were included in this longitudinal analysis if they had T2D, had completed at least one of the May, June, or July 2020 COPE surveys, were 18 years or older, had baseline body mass index (BMI) record prior to or in May 2020, and had complete data on all sociodemographic variables of interest. Cases of T2D were either self-reported or extracted from electronic health records using a phenotype algorithm that has been validated for retrieving T2D cases from electronic medical records (Pacheco, Thompson & NorthwesternUniversity, 2012). This phenotype algorithm allowed us to include patients who had T2D diagnosis codes, T2D medication, HbA1C results of >6.5%, fasting plasma glucose of 125 mg/dl, or random plasma glucose of 200 mg/dl, and no type 1 diabetes diagnostic codes in their EHR which is linked to the All of Us program. Diagnosis codes used to identify T2D cases in the EHR included International Classification of Disease (ICD) 9 codes: 250.X0, 250.X2, and ICD-10 codes: E11.X, E11.XX, E11.XXX, and E11.XXXX where X stands for any number from 0 to 9. We used structured query language (SQL) to extract the electronic health records cases of T2D in the Researcher Workbench of the *All of Us* program. Overall, 22,059 individuals with T2D with complete data on all sociodemographic variables were identified, out of whom 5348 completed at least one of the COPE surveys from May to July 2020 and were included in the final analysis.

2.4. Outcome measures

Depressive symptoms. Depressive symptoms were measured at three timepoints with the 9-item Patient Health Questionnaire (PHQ-9) (Kroenke et al., 2010). Each PHQ-9 item is measured on a 4-point Likert scale "0" (not at all) to "3" (nearly every day). Representative items of the PHQ-9 include "feeling down, depressed, or hopeless?" and "Poor appetite or overeating?". The instrument is scored by summing the scores of all the 9 items, with total scores ranging from 0 to 27. As recommended, items with missing responses were only imputed (with the mean score calculated from the remaining items) if the number of missing items for the participant were less than 3, otherwise, the total PHQ-9 score was coded as missing (Kroenke et al., 2010). Higher PHQ-9 scores indicate higher depressive symptoms. For descriptive purposes, the total PHQ-9 score was also dichotomized into "none-to-mild depressive symptoms" (0–9) and "moderate-to-severe depressive symptoms" (10–27).

Physical activity. Physical activity was measured at three time points with the short version of the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003). IPAQ assesses physical activity in the past 7 days by asking for the amount of time and number of days per week one engages in walking, vigorous, and moderate physical activities. Vigorous activities include heavy lifting, digging, aerobics, or fast bicycling. Moderate activities include carrying light loads, bicycling at a regular pace, or doubles tennis (Craig et al., 2003).

We processed IPAQ data by following the detailed guidelines described in the IPAQ manual (Forde, 2018). For instance, values of 15,

30, 45, 60 and 90 in the hours column (only present in the May 2020 COPE survey) were converted to 15, 30, 45, 60 and 90 min, respectively, in the minutes column; participants who skipped walking, moderate or vigorous days or minutes questions had their total IPAQ score coded as missing; participants with walking, moderate and vigorous time variables summing up to 960 min also had their total IPAQ score coded as missing to exclude data which are unreasonably high; and minutes of physical activity less than 10 min were recoded as 0. The total IPAQ score was expressed as metabolic equivalent task (MET) minute per week. The MET-minute/week score was obtained by using the formula (Hagströmer and Sjöström, 2006):

$$3.3\ X\ walking\ minutes\ X\ walking\ days + 4.0\ X\ moderate\ activity\ minutes\ X\ moderate\ activity\ days + 8.0\ X\ vigorous\ activity\ minutes\ X\ vigorous\ days.$$

An indicator variable was created for physical activity such that 1 = total IPAQ greater than or equal to 600 MET-minute per week (physically active) and 0 = total IPAQ less than 600 MET-minute per week (physically inactive). We chose 600 MET-minute per week as the cut-off point based on the IPAQ manual (Craig et al., 2003) and American Diabetes Association guidelines for physical activity in diabetes of 150 min/week of moderate activity (equivalent to 600 MET-minute/week) (Colberg et al., 2016).

Sociodemographic data. The following time-invariant sociodemographic data were included in this study: age, sex assigned at birth (recoded as male, female, Others), race and ethnicity (recoded as Non-Hispanic White, Non-Hispanic Black, Hispanic, Others), marital status (recoded as married or partnered, single, and widowed/separated/divorced), highest education (recoded as high school or less, some college education, college degree, and advanced degree), and annual income (recoded as less than $50,000, $50,000-$99,999, and $100,000 or more). The "other" race and ethnicity included Asian, Pacific Islanders, Middle Eastern/North African, identifying with more than one race, and those who "prefer not to say". The "other" sex at birth included those who identified as intersex, neither male or female, and those who "prefer not to say". All sociodemographic data were participant provided information and were collected via the "basic survey" that is administered to all participants at enrollment into the All of Us program. We focused on demographic data available between 2018 and 2020.

BMI. Height and weight were measured by trained staff using standard procedures. BMI were computed using the formula: weight (in kilograms)/[height (in meters)]^2. BMI was then recoded as normal [<25 kg/m^2], overweight [25.0 kg/m^2 – 29.9 kg/m^2, and obese [≥30 kg/m^2]). We only used the most recent BMI values measured in or prior to May 2020 (baseline) in the current analysis.

2.5. Statistical analysis

Data analysis was conducted in the Researcher Workbench of the *All of Us* program using R programming language. Descriptive statistics such as means, standard deviations, proportions, medians, and interquartile ranges were computed as appropriate. We compared the sociodemographic characteristics of our final analytic sample (N = 5348) with the cohort of persons with T2D from the larger *All of Us* program database who had baseline BMI record (N = 22,059). To address the healthy volunteer bias in completing the COPE surveys, we computed stabilized inverse probability weights (sIPW). The sIPW was determined by calculating the predicted probabilities that a person with T2D will complete the COPE survey at each of the three time points and finding the inverse of the product of all three probabilities. The probabilities of completing the survey were predicted by participants' age, sex, BMI categories, marital status, education, income, and race and ethnicity. Next, we assessed the longitudinal association between depressive symptoms as independent variable (continuous variable) and physical activity as outcome variable using sIPW-weighted mixed effect logistic regression model while adjusting for all sociodemographic and BMI data as covariates. All continuous variables in the model were mean-centered. The mixed effect model allowed us to accommodate for missing responses at certain timepoints. Lastly, we plotted the predicted probabilities of being physically active while highlighting interaction effects of the predictor with race and ethnicity and survey months. A p-value of 0.05 or less was considered statistically significant.

3. Results

3.1. Characteristics of study sample

Table 1 details the characteristics of study participants. Most participants were non-Hispanic White (76.25%), married or partnered (58.21%), women (56.49%), and had BMI ≥30 kg/m^2 (69.63%). Compared to the larger cohort of T2D individuals in the *All of Us* dataset, persons with T2D who completed the COPE survey were more likely to be non-Hispanic White (76.25% vs 50.67%), to be a college graduate (54.86% vs 34.38%), and have an income of $50,000 or more (59.58% vs 35.79%).

As shown in Fig. 1, the prevalence of moderate-to-severe depressive symptoms remained stable from May to June 2020, and then decreased slightly from 50% in June to 47% in July 2020. In contrast, the proportion of participants who were physically activity declined from May (20%) to June (18%) and remained stable from June to July. After stratifying by race and ethnicity, we observed that at baseline, non-Hispanic Blacks and Hispanics had significantly higher prevalence of moderate-to-severe depressive symptoms compared to non-Hispanic Whites (p = 0.0002). Hispanic participants reported a steady decline in physical activity rates whereas the proportion of Blacks and Whites

Table 1
Characteristics of study participants; Comparing COPE Survey Respondents with persons with T2D in the All of Us (AoU) program.

Characteristics	Persons with T2D who completed the COPE survey.	Persons with T2D in the overall AoU database[a]
	N = 5348	N = 22059
	N (%)	N (%)
Race and ethnicity		
Non-Hispanic White	4078 (76.25)	11178 (50.67)
Non-Hispanic Black	590 (11.03)	5910 (26.79)
Hispanic	393 (7.35)	3816 (17.30)
Other	287 (5.37)	1155 (5.24)
Marital status		
Single	836 (15.63)	4522 (20.50)
Married or partnered	3113 (58.21)	10264 (46.53)
Divorced/separated/widowed	1399 (26.16)	7273 (32.97)
Sex at birth		
Female	3021 (56.49)	12722 (57.67)
Male	2296 (42.93)	9220 (41.80)
Others	31 (0.58)	117 (0.53)
Education		
High school or less	680 (12.72)	7499 (33.69)
Some college education	1734 (32.42)	6976 (31.62)
College degree	1465 (27.39)	4117 (18.66)
Advanced degree	1469 (27.47)	3467 (15.72)
Income		
< $50,000	2162 (40.42)	14165 (64.21)
$50,000-$99,999	1681 (31.43)	4546 (20.61)
$100,000 or more	1505 (28.15)	3348 (15.18)
Body mass index		
Normal [<25 kg/m^2]	392 (7.33)	1891 (8.57)
Overweight [25.0 kg/m^2 – 29.9 kg/m^2]	1232 (23.04)	4996 (22.65)
Obese [≥30 kg/m^2]	3724 (69.63)	15172 (68.78)
Age in years (mean, SD)	61.43 (11.63)	59.00 (12.66)

[a] Includes persons with T2D who had baseline BMI in or before May 2020.

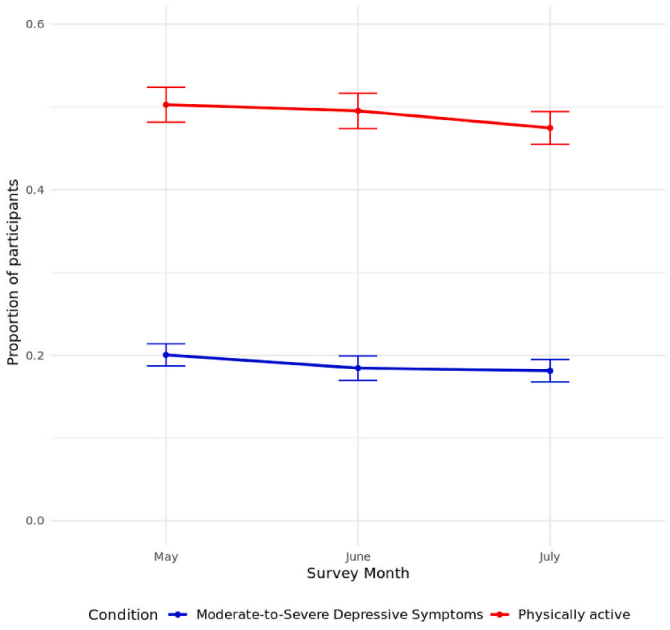

Fig. 1. Trends in the proportion of participants who are physically active and have moderate-to-severe depressive symptoms over time.

who were physically activity remained relatively stable (Supplementary Fig. S1).

3.2. Mixed effect logistics regression

The predicted probability of being physically active decreased with increasing depressive symptoms (Fig. 2). As shown in Table 2, participants who had higher depressive symptoms had 34% lower odds of being physically active (aOR = 0.66; 95%CI: 0.60, 0.73). We found a significant interaction between survey month and depressive symptoms. As shown in Fig. 3 and Supplementary Table S1, the association between depressive symptoms and physical activity was strongest in the month of July (p for interaction <0.0001). Similarly, we found a significant

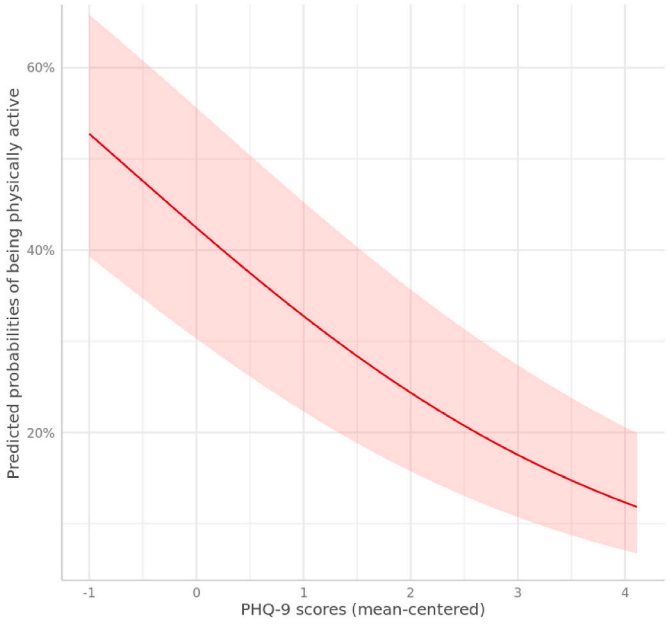

Fig. 2. Predicted probability of being physically active as depression scores increase.

Table 2
Inverse probability weighted mixed effect logistics regression model with physical activity as outcome.

Variable	Adjusted OR (95% CI)	p-value
Depressive symptoms		
Depressive symptoms (PHQ-9)	0.66 (0.60, 0.73)	<0.0001
Survey month		
May	[Reference]	
June	0.45 (0.37, 0.55)	<0.0001
July	0.89 (0.74, 1.08)	0.2546
Race and ethnicity		
Non-Hispanic White	[Reference]	
Non-Hispanic Black	0.67 (0.48, 0.94)	0.019
Hispanic	0.69 (0.48, 1.00)	0.051
Other	1.98 (1.21, 3.23)	0.007
Marital status		
Single	[Reference]	
Married or partnered	1.36 (0.94, 1.96)	0.104
Divorced/separated/widowed	1.09 (0.75, 1.58)	0.649
Sex at birth		
Female	[Reference]	
Male	2.16 (1.64, 2.83)	<0.0001
Others	0.33 (0.02, 5.92)	0.449
Education		
High school or less	[Reference]	
Some college education	1.50 (1.08, 2.08)	0.015
College graduate	2.53 (1.73, 3.69)	<0.0001
Advanced degree	3.72 (2.45, 5.64)	<0.0001
Income		
< $50,000	[Reference]	
$50,000-$99,999	1.48 (1.07, 2.03)	0.017
$100,000 or more	2.30 (1.55, 3.43)	<0.0001
Body mass index		
Normal [<25 kg/m^2]	[Reference]	
Overweight [25.0 kg/m2 – 29.9 kg/m2]	0.53 (0.31, 0.89)	0.016
Obese [≥30 kg/m2]	0.25 (0.15, 0.40)	<0.0001
Age	0.89 (0.78, 1.02)	0.383

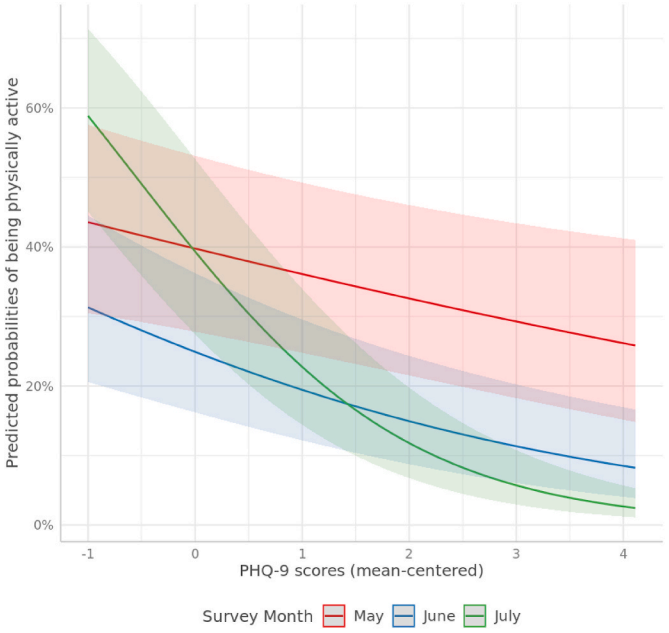

Fig. 3. Interaction effect between Survey Month and Depressive Symptoms.

interaction between depressive symptoms and race and ethnicity such that the inverse association between depressive symptoms and physical activity was strongest among non-Hispanic Whites. Specifically, as depressive symptoms increased, non-Hispanic Whites demonstrated a steeper decline in their predicted probability of being physically active compared to non-Hispanic Blacks and Hispanics (Fig. 4 and

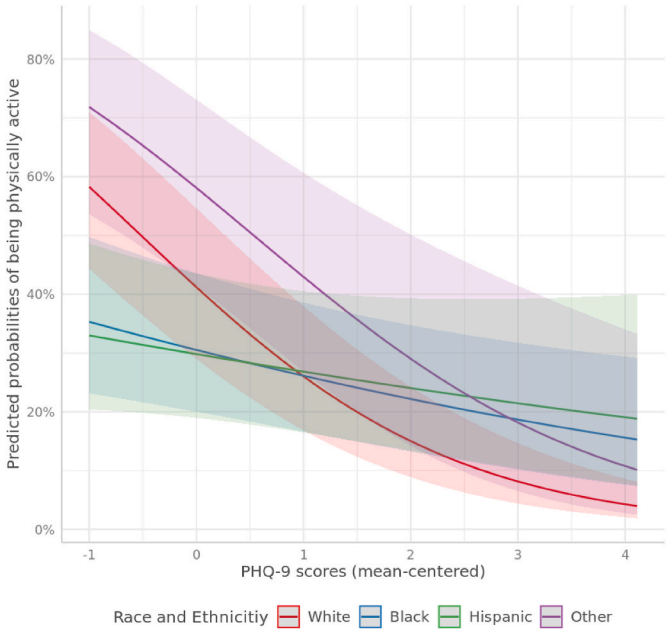

Fig. 4. Interaction effect between race and ethnicity and depressive symptoms.

Supplementary Table S2).

4. Discussion

This study examined the longitudinal effect of depressive symptoms on physical activity among individuals with T2D during the COVID-19 pandemic, offering valuable insights into how psychosocial factors, exacerbated by the pandemic, influence self-care behaviors in this vulnerable population. At baseline, we found that 50% of the study participants had moderate-to-severe depressive symptoms, while only 20% were physically active. We also identified a significant association between depressive symptoms and physical activity, wherein participants experiencing higher depressive symptoms were significantly less inclined to engage in physical activities over time. Furthermore, we found that the likelihood of not engaging in physical activity increased significantly across the timepoints investigated and was more pronounced among non-Hispanic White participants.

The prevalence of moderate-to-severe depressive symptoms in our study sample is markedly higher than previously reported in individuals with diabetes before the COVID-19 pandemic. For instance, in a nationally representative sample of US T2D participants in the National Health and Nutrition Examination Survey, Wang et al. (2016) reported a 10.6% prevalence of moderate-to-severe depressive symptoms. Koyama et al. (2023), using data from the Behavioral Risk Factor Surveillance System, also reported a 29.2% overall prevalence of depression in 55, 881 adults with diabetes sampled across all fifty states in the US. Considering that our data was collected during the COVID-19 pandemic, the elevated prevalence of depressive symptoms in our participants may reflect the added stressors and disruptions brought about by the pandemic.

Behavioral changes, including significant reductions in physical activity levels, were widely reported during the pandemic (Leite et al., 2022). Studies comparing pre- and post-pandemic data highlight this trend. For example, McCarthy et al. (2021) reported that 63% of individuals experienced a decrease in physical activity during lockdowns compared to pre-pandemic periods. In individuals with diabetes, Assaloni et al. (2020) documented a decrease in exercise time from 66 min pre-lockdown to 38 min during lockdown. Although our study did not compare pre- and post-pandemic physical activity, our findings align with this trend, as only 20% of participants reported engaging in any form of physical activity. This figure contrasts sharply with pre-pandemic engagement rates, which ranged from 39% to 67% in individuals with diabetes (Johnson et al., 2019; Morrato et al., 2007).

Several studies have found a significant association between depression and physical activity in individuals with T2D (Lysy et al., 2008; Sumlin et al., 2014; Mendes et al., 2019; Lai et al., 2022). Studies, using correlation analysis in exploring directionality, have revealed a negative impact of depression on physical activity in individuals with T2D, with the correlation coefficient (r) ranging from −0.17 to −0.46 (Sumlin et al., 2014). Using the sIPW-weighted mixed effect logistic regression model, we also identified a similar pattern, with individuals with T2D who had higher depressive symptoms having a 34% reduction in their tendency to engage in the recommended physical activity. Additionally, our study provided longitudinal evidence of this relationship, with the findings revealing that the impact of depression on physical activity increased consistently over the three months study period. Similar pattern has been reported in previous longitudinal studies conducted before the COVID-19 pandemic (Gonzalez et al., 2008; Ivanova et al., 2017). For instance, at 9-month follow-up, Gonzalez et al. (2008) found that the experience of depression was significantly associated with poorer adherence to physical activity. Ivanova et al. (2017) in their cohort study also reported that, at both 1 and 2-year post baseline follow-ups, symptoms of depression were associated with lower exercise frequency in individuals with T2D.

Several mechanisms, may underlie the observed association between depression and physical activity among individuals with T2D. Studies have shown that depression can lead to feelings of fatigue (Pouwer et al., 2013; Kraft et al., 2023), which can act as a barrier to engaging in physical activity. Moreover, a previous study has found that depression can diminish the sense of self-efficacy in individuals with T2D (Cherrington et al., 2010), which can erode their confidence in initiating and sustaining physical activity. Furthermore, recent study has revealed that depression is associated with cognitive impairment (including decline in memory and executive function) in individuals with diabetes (Chow et al., 2022). These cognitive deficits can interfere with the planning, initiation, and execution of goal-directed behaviors, including engaging in physical activity. The stressors introduced by COVID-19, such as lockdowns and social isolation, likely amplified these depressive symptoms in individuals with T2D, further reducing motivation and capacity to engage in physical activity. Moreover, previous research has established an inverse relationship between physical activity and depression (Pearce, Garcia, Abbas et al., 2022), suggesting that reduced physical activity may worsen mood, potentially creating a cyclical relationship between depression and inactivity. While these mechanisms provide a plausible explanation for the association observed in our study, it is important to note that this evidence has not been empirically examined in individuals with T2D. Therefore, further research is necessary to explore the underlying mechanisms and confirm the causal relationship between depression and physical activity in this population.

Our stratified analysis based on race and ethnicity revealed significant variations in the levels of depression and its impact on physical activity. Consistent with previous studies, we found that non-Hispanic Blacks and Hispanics, identified as ethnic minorities, exhibited a higher prevalence of moderate-to-severe depressive symptoms compared to non-Hispanic Whites (Bailey et al., 2019; Breland et al., 2023). However, our findings indicate that depressive symptoms in non-Hispanic White participants led to a more pronounced decrease in physical activity levels than those observed in ethnic minority groups. This is surprising given the consistent evidence that ethnic minorities are more likely to experience prolonged depression, which significantly impacts their daily functioning (Bailey et al., 2019). Considering the sense of solidarity and collective resilience found in many ethnic minority communities (Taylor et al., 2022), it is likely that these social factors may buffer the impact of depression on physical activity among these groups. Nonetheless, further research is warranted to empirically validate this assertion.

The findings from this study have important implications for healthcare practice and research. The high prevalence of moderate-to-severe depressive symptoms among individuals with T2D underscores the need for routine screening and management of depression in this population, especially during periods of heightened stressors such as the pandemic. Given the association between depression and physical activity, it is pertinent that interventions aimed at promoting physical activity among individuals with T2D incorporate strategies to address depressive symptoms. This may include cognitive-behavioral techniques to challenge negative thought patterns, stress management strategies, and social support networks to improve motivation and self-efficacy for physical activity (Xie & Deng, 2017; Franquez et al., 2023). The longitudinal nature of the association between depression and physical activity highlights the need for interventions that are tailored to provide ongoing support and encouragement over time. This may involve regular follow-ups, behavioral monitoring, and adjustment of intervention strategies based on individual progress and needs (Unützer & Park, 2012).

4.1. Limitations and strengths

This study has several limitations. First, the subjective measures used to assess physical activity may be prone to recall and social desirability biases. Future studies should consider using objective measures of physical activity including pedometers and Fitbit technologies. Second, the measurement of physical activity and depressive symptoms at the same time across all three months may limit our ability to fully conclude on the direction of effects between our dependent and outcome variables. Moreover, the relatively brief time frame investigated may not sufficiently capture chronic effects or long-term trends in either physical activity levels or depressive symptoms. Consequently, the results should be interpreted as a limited representation of participants' experiences rather than indicative of persistent changes over time. Third, while several studies have shown that the COVID-19 pandemic had significant impact on both physical activity and mental health, the lack of pre-pandemic data on the physical activity and depressive symptom variables in the *All of Us* dataset prevented us from determining if the associations among our variables were influenced by the pandemic. Lastly, there was evidence of response bias in the COPE survey with most survey respondents being non-Hispanic Whites. Although we used inverse probability weighting to account for this response bias, it is likely that the model used to generate IPW did not include all variables that can influence participation in the COPE survey. Despite these limitations, the large sample size, repeated measures for depressive symptoms and physical activity at three timepoints, and the use of inverse probability weighted regression analysis can be considered as strengths for this study.

5. Conclusions

Depressive symptoms were prevalent in persons with T2D and were significantly associated with lower odds of engaging in physical activity among this population during the period of the COVID-19 pandemic. Further longitudinal studies capturing pre- and post-pandemic data are needed to disentangle the effects of the pandemic from the underlying associations between depressive symptoms and physical activity.

CRediT authorship contribution statement

Emmanuel Ekpor: Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Data curation, Conceptualization. **Samuel Akyirem:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Precious Adade Duodu:** Writing – review & editing, Validation, Methodology, Formal analysis. **Jonathan Bayuo:** Writing – review & editing, Validation, Methodology, Formal analysis. **Veronica Brady:** Writing – review & editing, Validation, Supervision, Project administration.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mhpa.2024.100647.

Data availability

The data used for this study are available to approved researchers following registration, completion of ethics training and attestation of a data use agreement through the All of Us Research Workbench platform, which can be accessed via https://workbench.researchallofus.org/login.

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