Differences in Objectively Measured Daily Physical Activity Patterns Related to Depressive Symptoms in Community Dwelling Women - mPED Trial

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Research

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Abstract

Background: Physical activity(PA) has been identified as an effective depression treatment.However, knowledge on how variation in day-to-day PA relates to depression is lacking.

Purpose: The purposes of this cross-sectional analysis were to 1) compare overall objectively measured baseline daily steps and duration of moderate to vigorous PA (MVPA) and 2) examine differences in steps and MVPA on days of the week between women with high and low depressive symptoms, enrolled in the **m**obile phone based **p**hysical activity **ed**ucation (mPED) trial.

Methods:The Center for Epidemiological Studies Depression Scale was used to categorize low and high depressive symptom groups.We used linear mixed-effects models to examine the associations between steps and MVPA and depression-status both overall and by day of the week,adjusting for selected demographic variables and their interactions with day of the week.

Results:275 women were included in the final analysis, of which 217 had low and 58 had high depressive symptoms**.** We found that day of the week modified the associations of depression with both daily steps and MVPA. Women with high depressive symptoms were characterized by reduced activity at the end of the week (Friday: 832 fewer steps, 95% CI:116 to 1548, p=0.023; 8.9 lower MVPA, 95% CI:2.2 to 15.5, p=0.009), whereas women with low depression showed an increase in physical activity.

Conclusions: Day of the week might be an important target for personalization of physical activity interventions. Future work should evaluate potential causes of alterations in daily activity patterns in depression.

Trial Registration ClinicalTrials.gov#:NCTO1280812registered January 21, 2011

Introduction

Physical inactivity and depression are major global health problems. Both diseases are risk factors for many chronic illnesses, including cardiovascular disease[1], diabetes[2] and obesity[3,4]. The prevalence of both physical inactivity[5,6] and depression[7] in women is higher than in men. For example, in previous work the percentage of women that adhered to physical activity guidelines was 18% versus 22.9% in men measured by self-report in almost 400.000 US adults[8]. Further, a 2003 review estimated that the prevalence of lifetime depression is two times greater for women than for men[9].

A growing body of evidence shows that physical inactivity and depression are related[10,11]. For instance, in a meta-analysis of 25 studies, lower self-reported physical activity levels were significantly associated with a higher risk of subsequent depression.[12] Further, in a cohort study of over 30.000 healthy adults, individuals who did not engage in physical activity had a 44% increased risk of lifetime depression as compared to those with at least one hour of moderate or vigorous intensity physical activity (MVPA) per week[13]. Furthermore, engaging in regular physical activity significantly improved depressive symptoms and a higher duration and intensity of physical activity was also associated with greater improvement[14].

There is strong evidence that encouraging physical activity is a valuable mental health promotion strategy from a population health perspective as it may reduce the risk of developing clinical depression[12]. Both mobile health interventions[15] and face-to-face treatments[16] have shown moderate effect-sizes, though there effects seem to diminish over time[17]. In order to design effective physical activity interventions, we need to improve our understanding of physical activity patterns throughout the week in individuals with depressive symptoms. To date, most studies explored depression in relation to self-report measure of physical activity that are susceptible to both overestimation and underestimation of true physical activity levels due to social desirability and recall biases[18]. We also published a paper demonstrating a large discrepancy between self-reported physical activity and objectively measured activity[19] and also highlighted showed the inability to capture the absolute level of physical activity by self-report.

Physical activity patterns in individuals with no depressive symptoms appear to differ from day to day. For example, in youth, Wednesdays, Thursdays and Sundays were associated with a lower probability of meeting physical activity guidelines[20] based on self-report physical activity. Further, in urban adults in the United Kingdom, physical activity was lower on Sundays compared to weekdays and Saturdays[21] based on accelerometer data. In a 12-month study with Latina women using pedometers during a physical activity intervention, physical activity was higher on weekdays[22]. By contrast, one study in older adults using a body-fixed sensor to measure physical activity for seven days found no differences between weekend and weekday physical activity[23]. However, we do not know whether these findings can be generalizable to individuals with depressive symptoms.

The purposes of this cross-sectional analysis are 1) to compare differences in objectively measured baseline physical activity levels (total daily steps and duration of MVPA minutes per day) between women with high and low depressive symptoms who were enrolled in the mPED trial, and 2) to examine differences in the patterns of total daily steps and MVPA between the two groups on different days of the week (Monday through Sunday). We used baseline data of the **m**obile phone based **p**hysical activity **ed**ucation (mPED), a randomized controlled clinical trial (RCT) designed to evaluate the efficacy of a mobile app and accelerometer delivered physical activity intervention for physically inactive women

Methods

Study design and sample

In this cross-sectional analysis, we analyzed the sociodemographic, clinical, and self-reported questionnaires data collected at the screening/baseline study visit and accelerometer data collected during the run-in period prior to a randomization visit in the mPED trial. Detailed descriptions of the study design and outcomes have been previously published[24,25,26,27,28,29,30,31]. In short, eligibility criteria were female sex, age from 25 to 65 years, body mass index (BMI; calculated as weight in kilograms divided by height in meters squared) of 18.5 to 43.0, physically inactive at work and/or during leisure time based on the Stanford Brief Activity Survey, intent to be physically active, access to a home telephone or mobile phone, ability to speak and read English, no medical conditions or physical problems that required special attention in an exercise program, no current participation in other lifestyle modification programs, and no mild cognitive impairment as determined by the Mini-Cog test.

Procedures

During the screening/baseline visit, sociodemographics, medical and lifestyle history, the Center for Epidemiological Studies Depression Scale (CES-D)[32], body mass index (BMI) were assessed by a trained research staff. At the end of this visit, eligible participants were issued a run-in app and an accelerometer and brief training was provided to insure participants could successfully use both devices. During the run-in period, all participants were asked to use the study app, wear an Omron Active Style Pro HJA-350IT with triaxial accelerometer every day, and not to increase their activity. The run-in period lasted approximately 3 weeks. A run-in mobile phone app was created specifically for this phase of the study; it was designed to mimic the intervention app without any content to encourage or support increasing physical activity. Participants were instructed to enter an estimate of their daily step count into the app's daily activity diary every day of the run-in period.

Measures

Depressive symptoms

The Center for Epidemiological Studies Depression Scale (CES-D)[32] was used to assess self-reported depressive symptoms. The CES-D is a valid and reliable instrument that is widely used to assess depressive symptoms in a research context. A cutoff score of 16 is used to indicate risk for clinical depression. For the purpose of this analysis, women with CES-D scores ≥ 16 were considered "high depressive symptoms" and women with scores < 16 were considered "low depressive symptoms."

Objectively measured physical activity

The Omron Active Style Pro HJA-350IT with triaxial accelerometer was selected for this trial because it has well-established reliability and validity and records 150 days of daily activity data. The accelerometer was set to record and store physical activity (e.g. steps), but not to display the steps counts (only the current date and time were visible on the display). This accelerometer was programed to collect daily steps and physical activity intensity (metabolic equivalent values [METs]). The mean intensity value of a 1-minute epoch was calculated as the average value of six 10-second epochs. The METs determined by this accelerometer are closely correlated with METs calculated using energy expenditure measured by indirect calorimetry. Participants were asked to wear the this device all day, except when showering/bathing, swimming, or sleeping, from the time they got up in the morning until the time they went to bed at night for the duration of the run-in period. In order for accelerometer data to be valid for this analysis, participants has to wear the accelerometer for at least 8-hour per day for a minimum of 7 days. MVPA was defined as ≥ 3 metabolic equivalents (METs), based on the Compendium of Physical Activity [33]. To closely match with the 2018 Physical Activity Guidelines for Americans, total weekly minutes of MVPA were estimated as physical activity ≥ 3 METs lasting at least 1 min in duration.

Other measures

A research staff asked the participants to fill out the sociodemographic and medical from immediately after obtaining the written consent form. The emotional support question, " How many people can you count on to provide you with emotional support?", was developed by the research team. To calculate body mass index (BMI), weight was measured with a Tanita WB-110 digital electronic scale, and height was measured at baseline with a standard stadiometer.

Statistical Analysis

Descriptive statistics were used to summarize participant characteristics. Women with high/low depression were compared using t, Mann Whitney, chis-square and Fisher's exact tests as appropriate.

We used linear mixed models (LMMs) to examine whether women with high vs low depressive symptoms differed in average daily step counts and MVPA minutes per day. Based on prior evidence, we included self-reported emotional support, BMI, employment (paid work, yes or no), time in study, age, anti-depressant use, and day of the week as covariates in the model[34,35,36].We additionally corrected for daily time spent wearing the Omron device. We then examined modification of between-group differences by day of week using an augmented LMM adding interactions of depressive group as well as covariates with day of the week (Monday through Sunday). We used likelihood ratio (LR) tests to ensure adequate modeling of the covariance structure of the repeated outcomes, as recommended by Barr et al[37], first adding a random slope in study day to the initial random-intercept model, then further allowing for AR(1) residuals, as previous studies showed autocorrelation for physical activity patterns[38]. We also used LR tests to assess the need for more flexible modeling of secular trend in study day. Model assumptions were further checked by visual inspections of residual plots. Analyses were carried out in R studio V. 1.1.423 using the nmle package[39]. To estimate and plot marginal means (effects of independent variables adjusted for all other covariates and interactions), we used the ggeffects package[40].

Results

Participants

318 women came to the screening/baseline visit, but nine did not meet the eligibility criteria. The remaining 309 started the run-in period[29]. See Supplementary Flowchart. After removing participants who had less then 7 days in total of suitable data available (i.e. >8 hours recorded wearing time), 275 women were included in the analysis. Of these, 217 (78%) participants had low depressive symptoms (CESD < 16) and 58 (22%) participants had high depressive symptoms. Table 1. shows baseline characteristics with differences between high and low depression groups. High and low depression groups statistically differed on self-reported health ($p = 0.019$), antidepressant-use ($p = 0.018$), and emotional support ($p = 0.0013$).

Table 1
Univariate Comparisons of Participants with and without clinically significant depressive symptoms at baseline (n = 275)

	Low depressive symptoms (CES-D < 16) (n = 217)	**High depressive symptoms (CES-D < 16) (n = 58)**	**p-value**
Age Mean (SD)	52.3 (11.2)	49.2 (12.0)	0.065
Race/Ethnicity			0.39
Native Hawaiian/Pacific Islander	1 (0.5%)	0 (0%)	
Black/African-American	21 (9.7%)	5 (8.6%)	
Hispanic/Latino	13 (6.0%)	4 (6.9%)	
Asian	49 (22.6%)	10 (17.2%)	
White (non-Hispanic)	113 (52.1%)	34 (58.6%)	
More than 1 race	20 (9.2%)	5 (8.6%)	
Education			0.30
Completed High School & some college	55 (25.3%)	14 (24.1%)	
Completed College	82 (37.8%)	28 (48.3%)	
Completed Graduate School	80 (36.9%)	16 (27.6%)	
Household Income			0.47
Under 40,000	36 (16.6%)	14 (24.1%)	
40,001 to 75,000	52 (24.0%)	11 (19.0%)	
Over 75,000	112 (51.6%)	27 (46.6%)	
Don't know or Declined to state	17 (7.8%)	6 (10.3%)	
Marital status			0.51
never married	65 (30.0%)	21 (36.2%)	
currently married/cohabitating	106 (48.8%)	28 (48.3%)	
divorced/widowed	46 (21.2%)	9 (15.5%)	
Employment and shift work			0.19
Full or Part time Job No Shift Work	118 (54.4%)	27 (46.6%)	
Full or Part time Job with Shift Work	46 (21.2%)	10 (17.2%)	

	Low depressive symptoms (CES-D < 16) (n = 217)	High depressive symptoms (CES-D < 16) (n = 58)	p-value
No paid employment	53 (24.4%)	21 (36.2%)	
Used a pedometer prior to the study	100 (46.1%)	28 (48.3%)	0.88
Previously participated in a weight loss/diet program	129 (59.4%)	36 (62.1%)	0.83
Health variables			
Self-reported health (Mean, SD)	5.02 (1.05)	4.62 (1.15)	**0.019**
Antidepressant use (%)	41 (18.9%)	20 (34.5%)	**0.018**
Emotional support (Mean, SD)	2.80 (0.464)	2.53 (0.863)	**0.0013**
Body mass index, kg/m (Mean ,SD)	29.7 (6.05)	29.8 (6.38)	0.87
Self-reported high blood pressure (%)			0.29
No	154 (71.0%)	46 (79.3%)	
Yes	58 (26.7%)	12 (20.7%)	
Don't know	5 (2.3%)	0 (0%)	
Self-reported high cholesterol (%)			0.36
No	113 (52.1%)	36 (62.1%)	
Yes	72 (33.2%)	14 (24.1%)	
Don’t know	32 (14.7%)	8 (13.8%)	
Reached menopause (%)	59%	50%	0.25

Table 1.

Average daily steps and MVPA between the non-depressive and depressive groups

A total of 4887 days were available for the analysis with a mean available number of days of 17.7 (SD = 5.6) per participant. Overall, we did not find any significant differences in total average daily steps (estimate = 108.3 fewer steps, 95% CI -189 to 406.2, p = 0.47) and MVPA minutes (estimate = 1.45 minutes /per day lower MVPA, 95% CI -1.27 to 4.35, p = 0.28) in women with high compared to low depressive symptoms, after adjusting for covariates specified a priori. However, these effects were modified by day of week (both p = 0.02 for interaction), with lower activity most evident on Friday for women with high depressive symptoms (832 fewer steps, 95% CI: 116 to 1548, p = 0.023; 8.9 lower MVPA, 95% CI: 2.2 to

15.5, p = 0.009). These models were corrected for covariates specified a priori, and for interactions between these covariates and days of the week. Adjusted between-group differences extracted from these models overall, averaged over day of the week are shown in Figs. 1 and 2. Differences by day of the week between women with high and low depressive symptoms are shown in Figs. 3 and 4. The Supplemental Material shows the tables with the Type III (partial sum of squares) tests outcomes for all fixed effects of these four models.

Discussion

This study did not identify overall differences in objectively measured total amount of daily physical activity for women with high compared to low depressive symptoms. However, there was a significant interaction between depressive symptom groups and day of the week. Women with high depressive symptoms showed significantly reduced physical activity towards the end of the week, most pronounced on Fridays, even after adjusting for potential confounding factors such as employment, BMI, emotional support and age, and their interactions with day of the week.

Although many studies found a relation between overall levels of physical activity and depressive symptoms[10,11,36,41,42] of which most were measured by self-report physical activity, a few studies that used objectively measured physical activity also did not find this relationship[14,43]. The results of this study suggest that differences in physical activity in depression (when measured objectively) might not lie in the total amount of activity, but rather in the day-to-day differences in patterns of physical activity. Another explanation could be related to a selection bias. Individuals with higher depressive symptoms may be less likely to participate in the 12-month physical activity intervention trial than those with lower depressive symptoms. Indeed, the sample with high depressive symptoms (n = 58) was smaller than the sample with low depressive symptoms (n = 217). The women with high depressive symptoms in this study might have been more motivated to become physically active than a general population sample with high depressive symptoms outside of the context of a physical activity study. Moreover, we excluded women who were already physically active prior to the study. These sample selection criteria might contribute non-significant physical activity levels between the two groups.

Our finding of decreased physical activity towards the end of the week on Thursday and particularly Friday for women with high depressive symptoms may have several explanations. First, women with depression may engage less in recreational exercise activities during their free time, outside of standard work hours. Because Friday is the start of the weekend, this may particularly be a day of physical activity in the context of socializing. Some studies observed that physical activity in a club setting (sports club) or other organized activities are associated with lower depressive symptoms, opposed to exercising alone[44,18]. Further, leisure time physical activity, over non-leisure time, has been associated with lower odds of depression[45]. This suggests an important role of social physical activities: exercise that can be done in a social context such as in a group and physical activity that is perceived as enjoyable for mental health outcomes[46,44]. However, this explanation remains speculative, as we did not measure if participants engaged in social physical activities throughout the week or exercised alone.

We observed a decrease in physical activity on Sunday compared to weekdays in both the high and low depressive symptom groups. Lower physical activity, objectively measured, mainly in the weekend has been observed in previous work[21,22,36]. One study using objectively measured step counts found that participants with mild to severe depressive symptoms walked less that those with low depressive symptoms overall, and that for both groups physical activity declined in the weekend[28]. However, in contrast to our study findings, the study above did not examine physical activity differences on the different days throughout the week. Future work should assess the relation between physical activity patterns throughout the week and accompanying emotions, social and work-related activities in depression, for instance by combining accelerometer data with ecological mood monitoring and/or an activity dairy.

This research has potential implications for data-driven personalization of physical activity interventions for depression through apps or other digital tools. Currently, there are a few studies focusing on mobile health personalization. Some of these studies use machine learning to adapt the intervention content[47]. Our results provide preliminary evidence that for individuals with depression, day of the week might be an important factor for personalization. Improving personalization of physical activity interventions might increase the effectiveness of these interventions[47]. For example, content can be developed to specifically target increasing motivation towards the end of the working week, when individuals with depression may be less active. This is important as, though a wealth of research highlighted the benefits of physical activity on depression[48], previous work has also reported that physical activity interventions do not reduce depression[49], or that the effects of these interventions on depression diminish after longer follow-up periods[50].

Strengths And Limitations

Strengths of this work include the use of objectively measured physical activity in a relatively large sample of diverse women. To the best of our knowledge, this is the first study to report the specific patterns of objectively measured physical activity over different weekdays in relation to depressive symptoms. In addition, the accelerometer was set to not display the steps counts or other physical activity information (only the current date and time were visible on the display) during the run-in period. We believe that this display mode prevented participants increasing physical activity. Despite these strengths, there are limitations to this study. First, we included a sample of female adults aged 25–69 years from the San Francisco Bay Area. The San Francisco Bay Area offers an extensive public transportation network that does not require a car to access the research office. Thus, findings from this study may not be generalizable to men or children, or to women beyond the Bay Area. Second, while we adjusted for employment status in our analysis models (full-time/part-time versus no employment), we did not have physical activity information related to the nature or working hours of participants' jobs. Lastly, we lack information on the types of physical activity, for example whether participants engaged in social or individual physical activity or leisure versus no leisure time activity. This information may have shed more light on the nature of our findings.

Conclusion

We did not find differences in physical activity in women with high compared to low depressive symptoms in the total amount of physical activity, but instead in the daily patterns of physical activity. Day of the week might be an important target for personalization of physical activity interventions, with a relation between high depressive symptoms and low physical activity towards the end of the working week. Future work should evaluate potential causes of alterations in day-to-day physical activity patterns in depression.

Declarations

Ethics, consent and permissions

The study protocol was approved by the University of California, San Francisco (UCSF) Committee on Human Research and the mPED Data and Safety Monitoring Board (DSMB). All participants provided written consent and gave consent to publication prior to study enrollment.

Consent for publication:

Not applicable

Availability of data and materials:

Curated technical appendices, statistical code, and anonymized data supporting the conclusions of this article is available from the authors on request.

Competing of Interests

the authors report no competing interests.

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Author contributions:

Dr. Fukuoka designed and implemented the study and collected the data. Dr. Figueroa drafted the first version of the manuscript and conducted the quantitative analysis. Dr. Vittinghof supervised the statistical analysis. Dr. Aguilera assisted with interpreting the results of the analyses. All authors contributed to the writing of the final manuscript.

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Figures

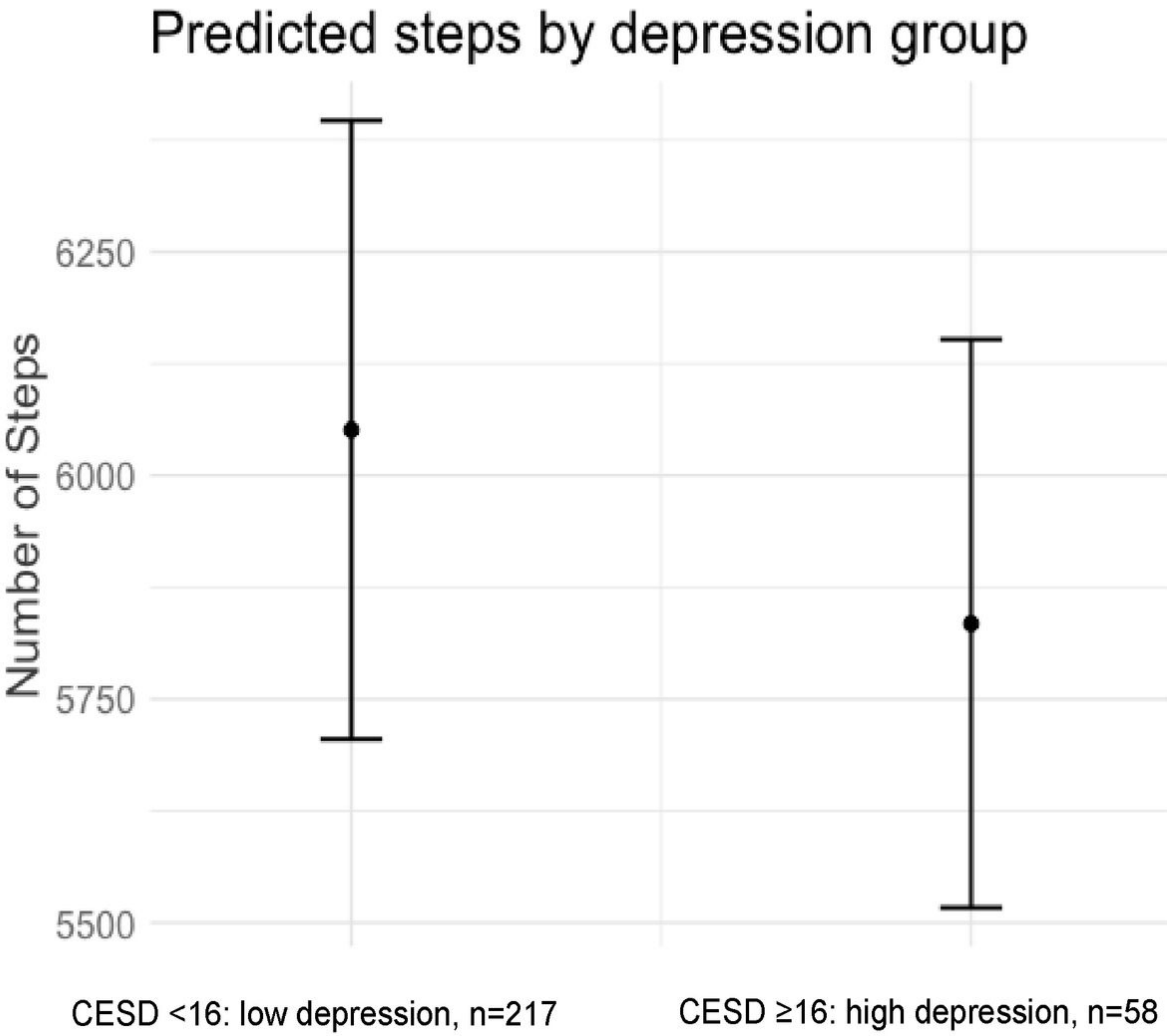

Figure 1

Marginal means plot for daily steps and depression groups

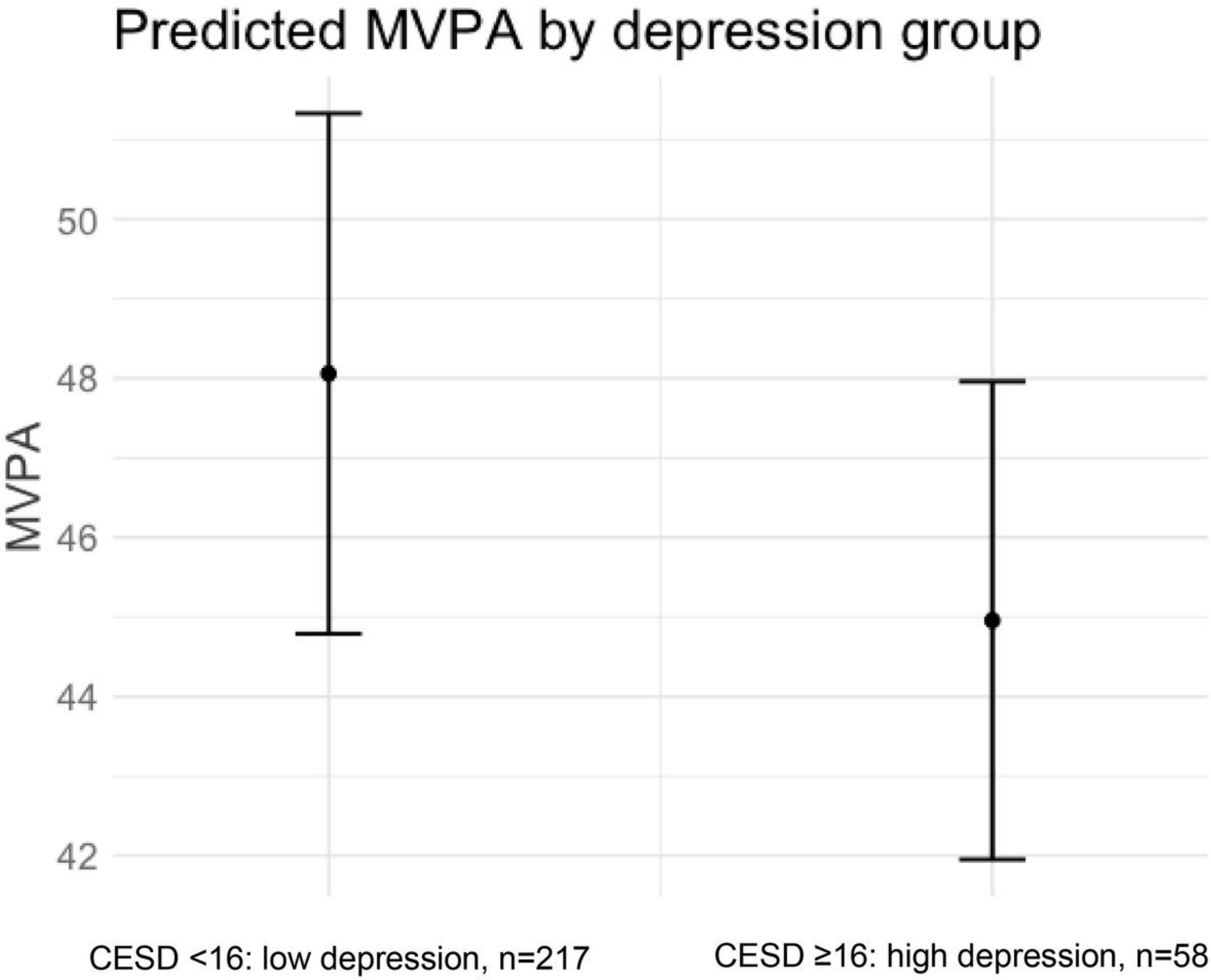

Figure 2

Marginal means plot for moderate to vigorous physical activity (MVPA) minutes per day and depression group.

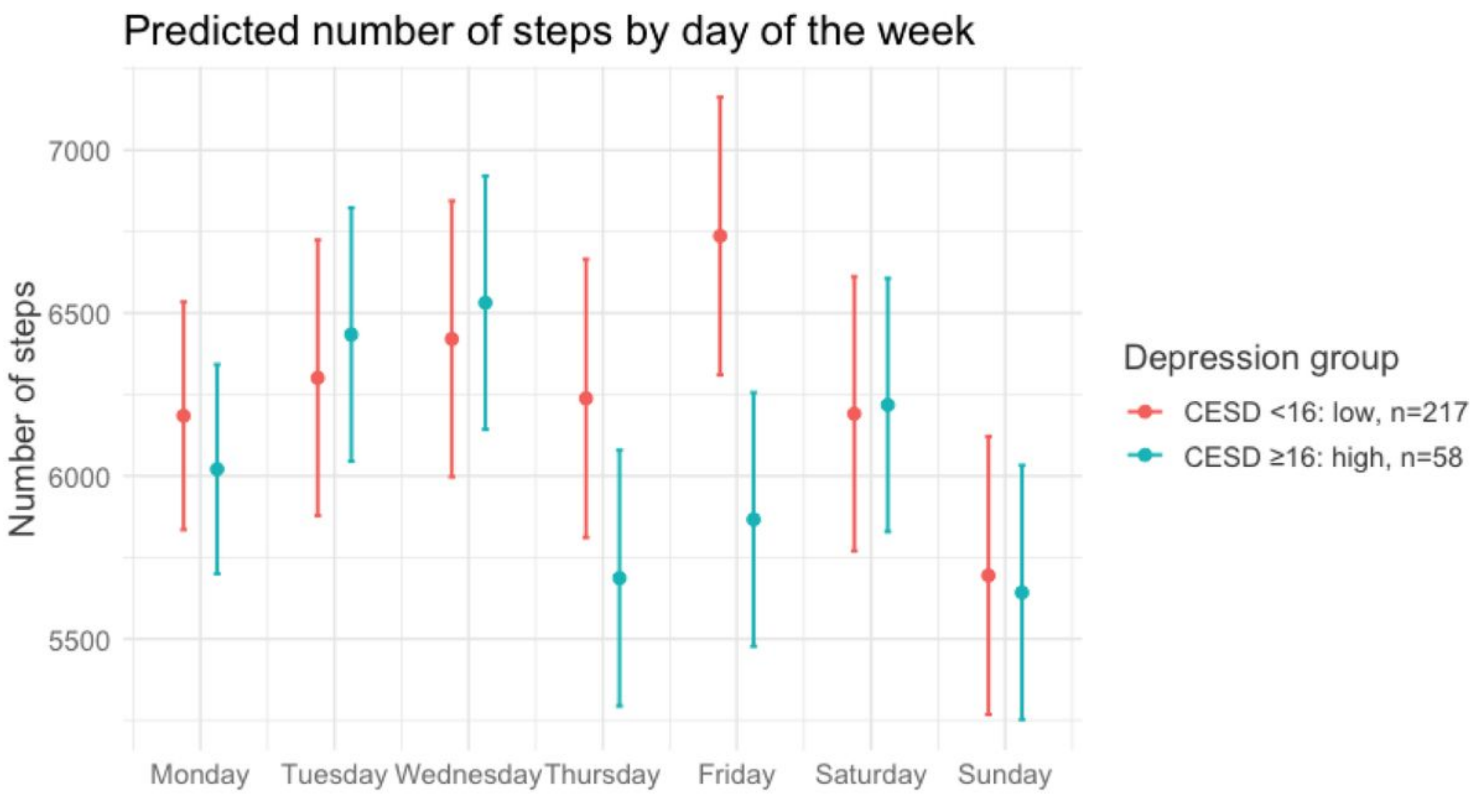

Figure 3

Marginal means plot for steps by day of the week and depression group

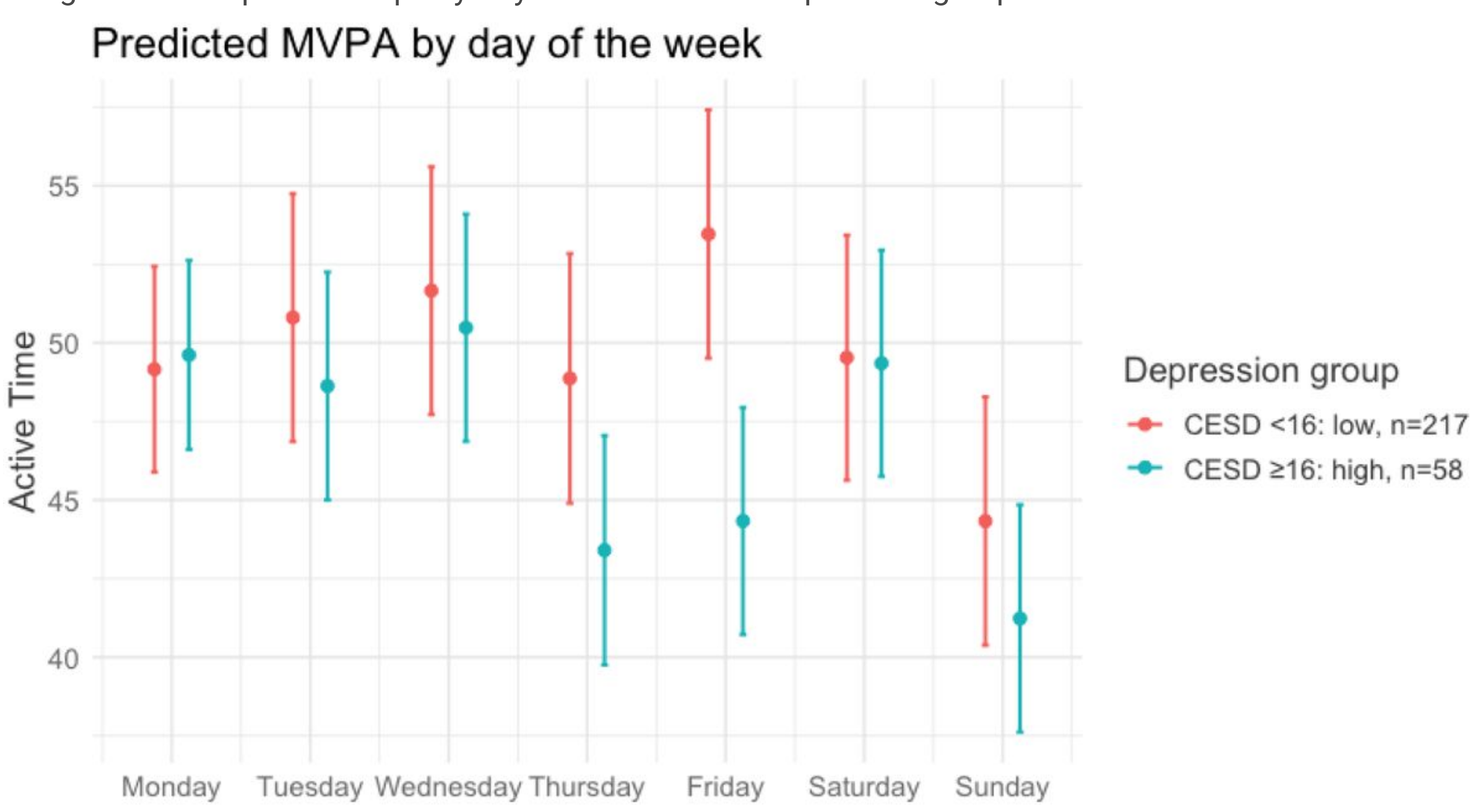

Figure 4

Marginal means plot for MVPA (minutes of moderate to vigorous physical activity) by day of the week and depression group

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementalMaterial.docx
- Supplementaryflowdiagram.docx