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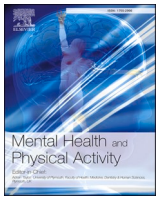

Physical activity and mental health in patients with multimorbidity

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ABSTRACT

Background and aims: Multimorbidity, defined as the presence of two or more chronic health conditions, is a growing problem in the United States and abroad. Physical activity is a modifiable health behavior that promotes physical and mental health, yet little is known about the relationship between physical activity and mental health among those with multimorbidity.

Methods: Using a population-based survey of community dwelling adults in Wisconsin, the Survey of the Health of Wisconsin (SHOW), we assessed the relationship between accelerometer-measured physical activity and self-reported depressive and anxiety symptoms among those with and without multimorbidity.

Results: Participants with multimorbidity were significantly more likely to have moderate to extremely severe levels of anxiety than those without multimorbidity (17.2% vs 10.5%, $p < 0.001$). One hour of moderate-to-vigorous physical activity (MVPA) per week was associated with decreased odds of anxiety of those with multimorbidity (0.86 [0.75, 0.99]). We also found a positive association between light intensity physical activity and a lower burden of depressive symptoms among those with one chronic condition (0.95 [0.93, 0.98]) or multimorbidity (0.97 [0.95, 1.00]), and lower odds of anxiety among those without chronic conditions (0.98 [0.95, 1.00]) or with only one chronic condition (0.95 [0.93, 0.98]).

Conclusions: Our study suggests that MVPA and light intensity physical activity may be associated with lower odds of elevated depressive and anxiety symptoms among those with and without multimorbidity. Further research is needed to identify populations, disease states, and condition clusters that may have the most potential benefit from light intensity activity and MVPA.

1. Introduction

Multimorbidity, defined as the presence of two or more chronic health conditions, is a growing problem in the United States and globally (Khanolkar et al., 2021; King et al., 2018; Zhang et al., 2021). Due in part to modern increases in unhealthy lifestyle behaviors like sedentary time and poor nutrition as well as early life stressors like poverty, multimorbidity poses immense challenges to the individual and the healthcare system (Khanolkar et al., 2021; King et al., 2018; Zhang et al., 2021). The presence of multimorbidity is associated with decreases in physical functioning and quality of life and increases in healthcare utilization, including higher rates of hospitalizations, longer hospital stays, greater amounts of pharmacological treatments, and higher healthcare costs (Skou et al., 2022; Lehnert et al., 2011; Vogeli et al., 2007). The 2014 National Health and Nutrition Examination Survey (NHANES) found that 59.6% of US adults had more than two chronic conditions (including obesity), which is a stark increase of almost 14% from 1988 (King et al., 2018). The aging of the US population will accelerate the individual-level problems and healthcare burden imposed by the growing prevalence of multimorbidity (Goodman et al., 2016).

Physical activity (PA) is a well-studied health behavior among healthy adults and in many single-condition chronic disease populations, such as adults with cancer or heart disease. However, less is understood about PA levels among individuals with multimorbidity. The

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relationship between PA and multimorbidity is likely bidirectional. Individuals with multimorbidity are significantly more likely to engage in low levels of physical activity (Vancampfort et al., 2017), and being physically inactive is also associated with an increased odds of multimorbidity (Roberts et al., 2015). Physical activity may also blunt the negative effects of multimorbidity. Higher activity levels are associated with lower mortality risk and an increased life expectancy among those with multimorbidity (Chudasama et al., 2019). Additionally, there is evidence of an interaction of PA and multimorbidity, where active individuals with multimorbidity glean greater benefits in the domains related to physical, mental, cognitive, and general health than active individuals without multimorbidity (Fessler et al., 2023).

The 2018 Physical Activity Guidelines for Americans call for individuals to engage in at least 150 min of moderate-intensity PA, or 75 min of vigorous-intensity PA, or some equivalent combination per week (Piercy et al., 2018). The guidelines also urge adults to do muscle-strengthening activities 2 or more times per week and encourage adults with chronic conditions to follow the guidelines to the extent that they are able (Piercy et al., 2018). Although most individuals with multimorbidity can safely engage in PA, some may have contraindications to exercise and thus be unable to safely perform the recommended amount (Pedersen & Saltin, 2015). Therefore, time spent in light intensity physical activity (LPA), and the potential health impacts of LPA, is of importance for this population. A 2016 cross-sectional analysis of NHANES data found that a 60-min per day increase of LPA was associated with 13% lower odds of multimorbidity, even after adjusting for moderate-vigorous physical activity (MVPA) (Loprinzi, 2016). A systematic review performed by Amagasa et al. (2018), showed that LPA may confer health benefits including improvements in mortality, triglyceride levels, diabetes, and metabolic syndrome prevalence, etc. after adjusting for MVPA.

In addition to decreases in physical functioning, individuals with chronic diseases and multimorbidity have an increased likelihood of developing depression and anxiety compared to those without chronic conditions (Gould et al., 2016; Read et al., 2017; Smith L et al., 2022). In these populations, depression is associated with both the incident development of chronic disease and with prevalent cases (Birk et al., 2019). A study by Andrade-Lima (2020) et al. showed that PA may attenuate the association between chronic disease and multimorbidity with more severe depressive symptoms among adults in Brazil. Additionally, among older adults, Loprinzi et al. (2013) found that objectively measured MVPA and LPA were associated with lower depression symptoms.

There is a paucity of research on the association between LPA and mental health in the growing population of individuals with multimorbidity. Additionally, few studies of multimorbidity have used direct measures of PA (e.g., accelerometry) (Christofoletti et al., 2021; Chudasama et al., 2019; Dankel et al., 2017). Since self-reported PA is often over-estimated when compared with objectively measured activity, this represents a major gap in the existing literature (Gorzelitz et al., 2018). The purpose of this study is to examine the association between objectively measured physical activity (including LPA) and the burden of reported depression and anxiety symptoms among adults with physical multimorbidity.

2. Materials and methods

We used data from the Survey of the Health of Wisconsin (SHOW), which is a novel, representative, population-based survey of Wisconsin residents to track trends in social, economic, and environmental factors that affect health and well-being. Since 2008, SHOW has collected self-reported and objective health data to provide a statewide geographic and demographic representation of Wisconsin residents. Study details have been discussed previously (Malecki et al., 2022; Nieto et al., 2010). The University of Wisconsin-Madison Health Sciences Institutional Review Board approved the study protocol and written informed consent was provided by all participants.

2.1. Variables

Physical activity was assessed using the ActiGraph wGT3X-BT (ActiGraph Corporation, Pensacola, FL). Participants received verbal and written instructions on proper use of the device and were instructed to wear the device on a belt on their right hip for all waking hours for 7 consecutive days, removing it only at night to sleep or for water-based activities (e.g., showering, swimming.) The devices were initialized to collect data in 1-s epochs, which were aggregated into 60-s epochs for wear time validation, scoring, and analysis. Accelerometer data were processed using ActiLife v6.13.3 (ActiGraph Corporation). The minimum valid wear time was 10 h per day for at least 3 out of 7 days. Our analytic sample included 1924 participants with sufficient wear time (1924/1985 = 96.9%) and 61 participants (61/1985 = 3.1%) were excluded from the analysis due to insufficient wear time. Physical activity intensity was defined using the Freedson Adult cutpoints of 0–99 counts/minute for sedentary, 100–1951 counts/minute for light, and 1952–5724 counts/minute for moderate, 5725–9498 counts/minute for vigorous, and ≥9499 counts/minute for very vigorous PA (Freedson et al., 1998). Participants who engaged in 150 min of moderate-intensity PA, or 75 min of vigorous-intensity PA, or some equivalent, were considered sufficiently active per the 2018 Physical Activity Guidelines for Americans (Piercy et al., 2018).

Health history was assessed by a trained interviewer using a computer-assisted personal interview (CAPI) form, which asked if a doctor or other health provider had ever diagnosed the participant with any of the following physical conditions: cancer, hyperlipidemia, diabetes, hypertension, coronary artery disease, heart failure, stroke, and chronic obstructive pulmonary disease (COPD). A history of coronary artery disease was defined as a history of a heart attack, coronary artery bypass grafting, or angioplasty. Physical multimorbidity was defined as the presence of two or more of the eight aforementioned conditions to be consistent with prior studies (Johnston et al., 2019). Patients were excluded if they were missing a history of two or more of the included conditions.

Depression and anxiety were assessed using the 21-item validated Depression Anxiety Stress Scales (DASS) (Norton, 2007). For binary logistic regression model outcomes, we assessed moderate to extremely severe levels of depression and anxiety. This is the cutpoint for depression and anxiety considered of clinical concern.

2.2. Analysis

All analyses were performed using Stata version 17.0 (College Station, Texas). Descriptive statistics are reported as count and percentage for discrete variables and as median (interquartile range) for continuous variables. Logistic regression models were used to assess the association between 1 h per week of time spent in LPA or MVPA with moderate to extremely severe levels of depression and anxiety. Additional models were stratified by being sufficiently active and the presence or absence of multimorbidity with a given condition. All models were adjusted for age, sex, body mass index, and current smoking status. Models of light intensity physical activity were also adjusted for weekly time spent in MVPA.

3. Results

Overall, 1924 SHOW participants with accelerometry data were included in the analysis. Descriptive statistics of the study population can be found in Table 1. The median age was 55 years (IQR: 41, 66) and 42.8% were male (n = 824). Non-Hispanic whites accounted for 79.1% participants (n = 1520). Only 37.3% of participants met the aerobic component of the national physical activity guidelines. Those who met the guidelines were less likely to have moderate to extremely severe

Table 1
Participant characteristics.

	Overall (n = 1924)	Missing n (%)
Age, median (IQR)	55 (41, 66)	0 (0)
Male, n (%)	824 (42.8)	0 (0)
Race/Ethnicity, n (%)		3 (0.2)
Non-Hispanic White	1520 (79.1)	
Non-Hispanic Black/African American	252 (13.1)	
Hispanic	65 (3.4)	
Non-Hispanic other or multiracial	84 (4.4)	
Urban/Rural RUCA Category, n (%)		3 (0.2)
Urban	1151 (59.9)	
Suburban	275 (14.3)	
Rural	495 (25.8)	
Diabetes, n (%)	222 (12.4)	135 (7.0)
Hypertension, n (%)	683 (35.6)	5 (0.3)
Cancer, n (%)	274 (14.3)	2 (0.1)
Hyperlipidemia, n (%)	679 (35.4)	8 (0.4)
Congestive Heart Failure, n (%)	63 (3.3)	1 (0.1)
Coronary Artery Disease, n (%)	109 (5.7)	3 (0.2)
Heart Attack	82 (4.3)	
CABG	42 (2.2)	
Angioplasty	30 (1.6)	
Stroke, n (%)	48 (2.5)	7 (0.4)
COPD, n (%)	122 (6.3)	4 (0.2)
Obesity, n (%)	853 (43.6)	0 (0)
BMI, median (IQR)	28.9 (24.9, 33.7)	0 (0)
Smoking History, n (%)		0 (0)
Current	272 (14.1)	
Former	550 (28.6)	
Never	1102 (57.3)	
DAS Scores		5 (0.3)
Depression (Mod-severe)	244 (12.7)	2 (0.1)
Anxiety (Moderate-severe)	244 (12.7)	1 (0.1)
Stress (Moderate-severe)	139 (7.2)	
Meets physical activity guidelines	717 (37.3)	0 (0)
Number of chronic conditions		0 (0)
0	778 (40.4)	
1	523 (27.2)	
≥2	623 (32.4)	

levels of anxiety (8.4% vs 15.3%, $p < 0.001$) and depression (9.9% vs 14.4%, $p = 0.005$). Physical multimorbidity was present in 32.4% participants (n = 623). The most common conditions associated with multimorbidity were hypertension (35.6%) and hyperlipidemia (35.4%). Moderate to extremely severe levels of depression and anxiety were present in 12.7% (n = 244) and 12.7% (n = 244) participants, respectively. Participants with multimorbidity were significantly more likely to have moderate to extremely severe levels of anxiety than those without multimorbidity (17.2% vs 10.5%, $p < 0.001$). There was no difference in the proportion of participants with moderate to extremely severe levels of depression with regards to multimorbidity.

3.1. Moderate to vigorous physical activity

One hour of MVPA per week was associated with decreased odds of anxiety among participants with multimorbidity (OR: 0.86 [95% CI: 0.75, 0.99]) as seen in Table 2. Additionally, this was observed among those with multimorbidity including hyperlipidemia (OR: 0.83 [95% CI: 0.70, 0.98]) and hypertension (OR: 0.82 [95% CI: 0.70, 0.98]). Moderate-to-vigorous physical activity was not significantly associated with lower odds of anxiety or depression among participants with other multimorbid conditions or number of conditions.

After stratifying by whether individuals met the national physical activity guidelines, we found that 1 h of MVPA was associated with lower odds of anxiety among those with multimorbidity who were insufficiently active (OR: 0.62 [95% CI: 0.40, 0.97]). Additionally, Table 3 shows that 1 h of MVPA per week was associated with lower odds of anxiety across all eight conditions for those without multimorbidity who were insufficiently active. Participants who had multimorbidity including hyperlipidemia and were insufficiently active also

Table 2
The association of 1-h MVPA of those with multimorbidity. Models were adjusted for age, sex, current tobacco use, and BMI.

Variable	Depression			Anxiety		
	n	OR	95% CI	n	OR	95% CI
Cancer	185	1.00	0.78, 1.30	187	0.93	0.73, 1.19
Diabetes	189	0.86	0.63, 1.17	189	0.95	0.77, 1.19
Hyperlipidemia	498	0.94	0.81, 1.09	498	**0.83**	**0.70, 0.98**
Hypertension	505	0.97	0.85, 1.11	506	**0.82**	**0.70, 0.98**
CAD	98	1.06	0.79, 1.42	99	0.73	0.45, 1.20
Heart Failure	57	0.72	0.36, 1.45	56	0.71	0.39, 1.28
Stroke	46	0.51	0.16, 1.60	46	0.55	0.19, 1.61
COPD	93	0.77	0.50, 1.21	93	0.89	0.65, 1.22
Number of chronic conditions						
0	776	0.95	0.86, 1.05	777	0.98	0.89, 1.08
1	523	0.91	0.80, 1.04	523	0.90	0.78, 1.05
≥2	620	0.92	0.80, 1.05	622	**0.86**	**0.75, 0.99**

Table 3
The association of 60 min of MVPA on predicting depression and anxiety. Models were stratified by the presence of multimorbidity including the specified condition (Yes versus No) and whether the participant met the physical activity guidelines (Active versus Inactive). Models were adjusted for age, sex, current tobacco use, and BMI.

	Depression			Anxiety		
Variable	n	OR	95% CI	n	OR	95% CI
Cancer						
No + Active	677	1.00	0.91, 1.10	676	1.05	0.97, 1.13
No + Inactive	1055	0.82	0.62, 1.09	1057	**0.61**	**0.45, 0.81**
Yes + Active	39	NA		40	1.67	0.51, 5.47
Yes + Inactive	146	**0.26**	**0.07, 0.91**	147	0.81	0.38, 1.74
Diabetes						
No + Active	642	1.03	0.94, 1.11	641	1.07	1.00, 1.15
No + Inactive	955	0.76	0.57, 1.03	958	**0.70**	**0.51, 0.95**
Yes + Active	33	0.42	0.13, 1.39	33	0.86	0.52, 1.43
Yes + Inactive	156	0.76	0.29, 2.02	156	0.68	0.28, 1.60
Hyperlipidemia						
No + Active	589	0.99	0.89, 1.10	589	1.06	0.98, 1.14
No + Inactive	824	0.80	0.58, 1.10	827	**0.71**	**0.51, 0.99**
Yes + Active	124	1.30	0.97, 1.74	124	1.06	0.76, 1.47
Yes + Inactive	374	0.68	0.40, 1.17	374	**0.52**	**0.31, 0.88**
Hypertension						
No + Active	598	1.00	0.90, 1.10	598	1.06	0.98, 1.14
No + Inactive	811	**0.72**	**0.53, 0.99**	813	**0.68**	**0.49, 0.94**
Yes + Active	118	1.26	0.93, 1.70	118	0.99	0.71, 1.39
Yes + Inactive	387	0.97	0.58, 1.62	388	0.61	0.36, 1.02
CAD						
No + Active	702	1.01	0.93, 1.10	701	1.05	0.98, 1.13
No + Inactive	1116	**0.75**	**0.57, 1.00**	1119	**0.66**	**0.50, 0.88**
Yes + Active	14	NA		15	NA	
Yes + Inactive	84	2.96	0.85, 10.33	84	0.46	0.10, 2.10
Heart Failure						
No + Active	705	1.02	0.94, 1.11	705	1.05	0.98, 1.13
No + Inactive	1156	0.79	0.60, 1.03	1160	**0.67**	**0.51, 0.89**
Yes + Active	11			11	NA	
Yes + Inactive	46	0.68	0.10, 4.47	45	0.19	0.02, 1.59
Stroke						
No + Active	710	1.01	0.93, 1.10	710	1.05	0.97, 1.13
No + Inactive	1156	0.78	0.59, 1.03	1159	**0.63**	**0.48, 0.84**
Yes + Active	5	NA		5	NA	
Yes + Inactive	41	1.06	0.21, 5.51	41	0.99	0.21, 4.63
COPD						
No + Active	703	1.02	0.93, 1.11	703	1.05	0.97, 1.13
No + Inactive	1119	0.83	0.62, 1.10	1122	**0.65**	**0.48, 0.87**
Yes + Active	13	NA		13	NA	
Yes + Inactive	80	0.56	0.19, 1.65	80	0.82	0.34, 2.02
Number of chronic conditions						
0 + Active	393	1.00	0.87, 1.14	392	1.05	0.95, 1.17
0 + Inactive	383	1.06	0.64, 1.74	385	0.94	0.55, 1.61
1 + Active	180	0.97	0.81, 1.17	180	1.06	0.95, 1.17
1 + Inactive	343	0.72	0.44, 1.16	343	0.69	0.41, 1.15
≥2 + Active	143	1.24	0.94, 1.65	144	1.02	0.77, 1.35
≥2 + Inactive	477	0.76	0.48, 1.20	478	**0.62**	**0.40, 0.97**

had lower odds of anxiety (OR: 0.52 [95% CI: 0.31, 0.88]). Lower odds of depression were found among those who were insufficiently active for those who had multimorbidity including cancer (OR: 0.26 [95% CI: 0.07, 0.91]), and those without multimorbidity including hypertension (OR: 0.72 [95% CI: 0.53, 0.99]) or CAD (OR: 0.75 [95% CI: 0.57, 1.00]). MVPA was not associated with depression or anxiety among those who met the national physical activity guidelines, regardless of their multimorbidity status.

3.2. Light intensity physical activity

Light intensity physical activity was also associated with lower odds of depression for those with one chronic condition (OR: 0.95 [95% CI: 0.93, 0.98]) and for those with multimorbidity (OR: 0.97 [95% CI: 0.95, 1.00]) (Table 4). Additionally, LPA was associated with decreased odds of anxiety among those without any chronic conditions (OR: 0.98 [95% CI: 0.95, 1.00]) and those with only one chronic condition (OR: 0.95 [95% CI: 0.93, 0.98]). However, there was no association between LPA and anxiety for those with multimorbidity. When examining the effects of 1 h per-week of LPA among participants with multimorbidity with specific disorders, we found a lower odds of depression among those with multimorbidity consisting of cancer and at least one other condition (OR: 0.94 [95% CI: 0.89, 0.99]). No other specific disorders within multimorbidity were associated with anxiety or depression.

Examining the effects of meeting the national physical activity guidelines, 1 h of LPA was associated with decreased odds of both depression (OR: 0.96 [95% CI: 0.94, 0.99]) and anxiety (OR: 0.97 [95% CI: 0.95, 1.00]) among those with multimorbidity who were insufficiently active (Table 5). A similar trend was found for those who were insufficiently active with only one chronic condition, with odds ratios of 0.96 [95% CI: 0.93, 0.99] for depression and 0.94 [95% CI: 0.91, 0.97] for anxiety. Decreased odds of anxiety were also associated with LPA for those with zero chronic conditions and were insufficiently active (OR: 0.96 [95% CI: 0.93, 0.99]). Additionally, 1 h per week of LPA was associated with lower odds of both depression and anxiety among those who were insufficiently active and did not have multimorbidity across all eight conditions. However, for those who were insufficiently active and had multimorbidity, only multimorbidity including cancer had lower odds of depression (OR: 0.91 [95% CI: 0.86, 0.97]) for every 1 h per-week increase of LPA.

4. Discussion

Our study examined the association between objectively measured light and moderate-to-vigorous intensity physical activity and reported depressive and anxiety symptoms. Our results show that among those with physical multimorbidity, the odds of anxiety were decreased with only 1 h per week of MVPA. This finding is consistent with other studies and populations, including among community-dwelling elderly adults, those with diagnosed anxiety disorders, and others with disabilities and disorders (Battalio et al., 2020; Chen et al., 2015; de Oliveira et al., 2019; Mochcovitch et al., 2016; Rajoo et al., 2019; Ramos-Sanchez et al., 2021).

Light-intensity physical activity and MVPA were found to have positive associations with lower reported depressive and anxiety symptoms among individuals who were insufficiently active with or without multimorbidity. In our study, individuals who met the aerobic component of the physical activity guidelines had lower proportions of moderate to extremely severe levels of anxiety and depression than those who were insufficiently active which may be influencing this finding. Additionally, given the noted benefits of MVPA on depression and anxiety symptoms, it is plausible that active individuals are already gleaning mental health benefits, so additional time spent engaging in MVPA or LPA does not result in additional benefits. A meta-analysis of

Table 4
The association of 1-h of light intensity physical activity among those with multimorbidity: Models were adjusted for age, sex, current tobacco use, BMI, and hours spent in MVPA.

Variable	Depression			Anxiety		
	n	OR	95% CI	n	OR	95% CI
Cancer	185	**0.94**	**0.89, 0.99**	187	0.98	0.94, 1.02
Diabetes	189	0.97	0.93, 1.02	189	0.99	0.95, 1.02
Hyperlipidemia	498	0.98	0.95, 1.01	498	0.98	0.96, 1.01
Hypertension	505	0.98	0.95, 1.01	506	0.98	0.95, 1.00
CAD	98	1.01	0.96, 1.07	99	1.01	0.96, 1.06
Heart Failure	57	0.98	0.90, 1.06	56	0.96	0.89, 1.04
Stroke	46	0.96	0.89, 1.04	46	0.98	0.92, 1.05
COPD	93	0.98	0.93, 1.02	93	0.97	0.93, 1.02
Number of chronic conditions						
0	776	0.99	0.97, 1.01	777	**0.98**	**0.95, 1.00**
1	523	**0.95**	**0.93, 0.98**	523	**0.95**	**0.93, 0.98**
≥2	620	**0.97**	**0.95, 1.00**	622	0.98	0.96, 1.00

Table 5
The association of 60 min of light intensity physical activity on predicting depression and anxiety. Models were stratified by the presence of multimorbidity including the specified condition (Yes versus No) and whether the participant met the physical activity guidelines (Active versus Inactive). Models were adjusted for age, sex, current tobacco use, BMI, and hours spent in MVPA.

	Depression			Anxiety		
Variable	n	OR	95% CI	n	OR	95% CI
Cancer						
No + Active	677	0.98	0.96, 1.00	676	1.00	0.97, 1.03
No + Inactive	1055	**0.97**	**0.95, 0.99**	1057	**0.96**	**0.94, 0.97**
Yes + Active	39	NA		40	1.06	0.95, 1.19
Yes + Inactive	146	**0.91**	**0.86, 0.97**	147	0.97	0.92, 1.01
Diabetes						
No + Active	642	0.99	0.96, 1.01	641	1.01	0.99, 1.04
No + Inactive	955	**0.96**	**0.95, 0.98**	958	**0.95**	**0.93, 0.97**
Yes + Active	33	0.91	0.78, 1.07	33	0.97	0.89, 1.05
Yes + Inactive	156	0.96	0.91, 1.01	156	0.99	0.95, 1.03
Hyperlipidemia						
No + Active	589	0.98	0.95, 1.01	589	1.01	0.98, 1.03
No + Inactive	824	**0.96**	**0.95, 0.98**	827	**0.95**	**0.93, 0.97**
Yes + Active	124	1.02	0.97, 1.09	124	0.99	0.93, 1.05
Yes + Inactive	374	0.97	0.93, 1.00	374	0.97	0.95, 1.00
Hypertension						
No + Active	598	0.98	0.96, 1.01	598	1.01	0.99, 1.04
No + Inactive	811	**0.96**	**0.94, 0.98**	813	**0.95**	**0.93, 0.97**
Yes + Active	118	1.01	0.95, 1.08	118	0.96	0.89, 1.03
Yes + Inactive	387	0.98	0.95, 1.01	388	0.98	0.95, 1.00
CAD						
No + Active	702	0.99	0.96, 1.01	701	1.00	0.98, 1.03
No + Inactive	1116	**0.96**	**0.94, 0.98**	1119	**0.95**	**0.94, 0.97**
Yes + Active	14	NA		15	NA	
Yes + Inactive	84	1.05	0.99, 1.11	84	1.00	0.95, 1.05
Heart Failure						
No + Active	705	0.99	0.96, 1.01	705	1.00	0.98, 1.03
No + Inactive	1156	**0.97**	**0.95, 0.98**	1160	**0.96**	**0.94, 0.98**
Yes + Active	11	NA		11	NA	
Yes + Inactive	46	0.99	0.92, 1.07	45	0.96	0.89, 1.03
Stroke						
No + Active	710	0.98	0.96, 1.01	710	1.00	0.98, 1.03
No + Inactive	1156	**0.97**	**0.95, 0.98**	1159	**0.96**	**0.94, 0.97**
Yes + Active	5	NA		5	NA	
Yes + Inactive	41	0.96	0.89, 1.03	41	0.98	0.92, 1.05
COPD						
No + Active	703	0.98	0.96, 1.01	703	1.00	0.98, 1.03
No + Inactive	1119	**0.97**	**0.95, 0.98**	1122	**0.96**	**0.94, 0.97**
Yes + Active	13	NA		13	NA	
Yes + Inactive	80	0.96	0.92, 1.01	80	0.97	0.93, 1.02
Number of chronic conditions						
0 + Active	393	1.00	0.97, 1.03	392	1.00	0.97, 1.03
0 + Inactive	383	0.97	0.95, 1.00	385	**0.96**	**0.93, 0.99**
1 + Active	180	**0.92**	**0.86, 0.97**	180	1.06	0.99, 1.14
1 + Inactive	343	**0.96**	**0.93, 0.99**	343	**0.94**	**0.91, 0.97**
≥2 + Active	143	1.01	0.96, 1.07	144	0.99	0.94, 1.04
≥2 + Inactive	477	**0.96**	**0.94, 0.99**	478	**0.97**	**0.95, 1.00**

randomized trials found that the effect size of physical activity on anxiety follows a quadradic trend, increasing as one approaches 12.5 kcal kg^{-1}·$week^{-1}$, but then decreasing after that point (Wipfli et al., 2008).

We also found a positive association between LPA and a lower burden of depressive symptoms among those with one chronic condition or multimorbidity, and lower odds of anxiety among those without chronic conditions or with only one condition. Our results are consistent with Loprinzi et al. (2013) as they found a 20% reduction in odds of depression for every 60-min increase of LPA among adults over the age of 65, although our results are more attenuated. However, this difference could be partly explained by methodological differences in the tool used to measure depression and their population being limited to older adults. Our findings also align with the findings of Hamer et al. (2014), which found that objectively measured LPA was associated with a lower risk of psychological distress in adults. A systematic review by Felez-Nobrega et al. (2021) found that LPA is not associated with better mental health measures across ages in the general population. However, certain populations, including older adults, who typically have a higher prevalence of multimorbidity, showed mixed results with regard to depression. Results in longitudinal studies are mixed. Two longitudinal studies assessed LPA and depressive symptoms and both found significant associations between the two (Ku et al., 2018; Uemura et al., 2018). However, another study found null results when looking at the association longitudinally despite a positive association in a cross-sectional assessment (Ribeiro et al., 2017). This discrepancy between the cross-sectional assessment and longitudinal findings may be in part related to the presence of a significant interaction between PA and fruit and vegetable intake, which was found in both assessments. Additionally, a cross-sectional study utilizing an isotemporal substitution model found that replacing 30 min/day of sedentary behavior with LPA was associated with a lower burden of depressive symptoms in older adults (Yasunaga et al., 2018). The mixed results across studies may be a result of differences in assessing PA intensities, as it has been found that self-reported measures of physical activity may be inconsistent with objective measures of physical activity (e.g. accelerometry), and thus obscure the relationship between PA and depression (Choi et al., 2019). It is also worth noting that the relationship between PA and depression is likely bidirectional. Adults with depressive symptoms may be less likely to engage in PA, and in turn, inactivity may impact their burden of mental health symptoms (Merikangas et al., 2019; Zhao et al., 2023). This relationship is also influenced by other factors, such as nutrition, sleep duration, and individual fatigue, and further research to disentangle these relationships is needed (Merikangas et al., 2019).

Participation in LPA may also have benefits for cognitive function. One study from the Tasmanian Older Adult Cohort Study found that LPA, but not MVPA or sedentary time, was associated with higher executive functioning and task switching among community-dwelling older adults (Johnson et al., 2016). Similarly, LPA was associated with improved cognitive function and decreased odds of cognitive impairment amongst older Taiwanese adults after adjusting for MVPA (Hsiao et al., 2022). However, further research specifically looking at mental health outcomes, other cognitive functions, and the population with multimorbidity is needed.

The current national physical activity guidelines only have recommendations regarding MVPA. However, our study presents some positive associations between 7-day LPA and lesser anxiety and depressive symptom burdens among those with chronic disease and multimorbidity, particularly if one is insufficiently active. Further research is still needed to assess other potential health benefits from LPA, which may present a better alternative for those with multimorbidity, for whom intense exercise can be limited due to safety concerns (Dekker et al., 2019). Additionally, depending on their presentation or treatment status, some individuals with chronic diseases, including coronary heart disease, heart failure, cancer, etc., may have contraindications to exercise at the intensities currently recommended by the national guidelines (Pedersen & Saltin, 2015), or may not be motivationally ready or interested in MVPA. As such, LPA could present as a more achievable means of improving health outcomes. Increasing PA levels among the insufficiently active may provide a cost-effective way of reducing some of the healthcare costs associated with aging and chronic disease. Future research is needed to further investigate these associations, in particular longitudinal studies that assess PA and mental health outcomes over time to better understand the directionality and any temporality with regard to the relationship.

There has also been some work done to understand the influence of intrasystem versus intersystem multimorbidity. Chronic conditions are classified by subgroups pertaining to the affected body system under the International Classification of Diseases, Tenth Revisions (ICD-10). As such, a study performed by Li et al. utilized these system classifications to examine the role of both types of multimorbidity in a Chinese cohort (Li et al., 2022). They found that both intrasystem multimorbidity and some combinations of intersystem multimorbidity affect the amount of leisure-time PA performed. Additionally, there was a synergistic effect of some combinations of intersystem multimorbidity increasing odds of low PA, and specifically affecting individuals with respiratory-metabolic or circulatory-respiratory multimorbidity (Li et al., 2022). As such, future research may also consider the role of intersystem versus intrasystem multimorbidity on outcomes and whether clusters of systems or conditions differentially affect outcomes.

Strengths of this study include the use of accelerometer-measured PA, which mitigates the potential for social desirability bias that can arise when using self-reported PA. Potential study limitations include creating the physical multimorbidity variable from a self-reported history, which may be subject to recall bias. In this case, it is more likely that this study is underreporting the association due to a lack of reporting chronic conditions (Muggah et al., 2013). Whether participants were meeting the muscle-strengthening components of the physical activity guidelines was not assessed and is a limitation of this study. The cross-sectional design of this study is also a limitation as it limits the ability to discern the directionality of the association, and it is plausible that this association is bidirectional such that adults with anxiety or depressive symptoms may be less likely or able to engage in PA, as well as inactivity impacting mental health symptoms. Another limitation of the study is the lack of adults with multimorbidity associated with certain disorders meeting physical activity guidelines, which limits study power. Our limited number of conditions, particularly those affecting the respiratory and digestive systems, impact our ability to assess the influence of intersystem and intrasystem multimorbidity. Finally, the lack of consensus on what diseases are included in the definition of multimorbidity will also affect the generalizability of our results.

5. Conclusion

In conclusion, our study suggests that MVPA and LPA may be associated with lower odds of having elevated depressive and anxiety symptoms among those with and without physical multimorbidity. In particular, those who are currently insufficiently active according to the national physical activity guidelines may see the most benefit from incorporating light and/or moderate-to-vigorous physical activity into their lifestyle. Further research is necessary to identify populations, disease states, and groups of multimorbid conditions that may have the most potential benefit from LPA and MVPA. Additionally, longitudinal examination of the effect of PA on mental health, cognitive functions, and other health outcomes is needed to understand the temporality of these associations and identify the optimal timing for future interventions.

CRediT authorship contribution statement

Christian W. Schmidt: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Megan**

Agnew: Writing – review & editing. **Kristen Malecki:** Writing – review & editing, Project administration, Investigation. **Ronald Gangnon:** Writing – review & editing, Formal analysis. **Amy Schultz:** Writing – review & editing, Project administration, Investigation. **Paul E. Peppard:** Writing – review & editing, Project administration, Investigation. **Lisa Cadmus-Bertram:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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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Data availability

The authors do not have permission to share data.

References

Battalio, S. L., Huffman, S. E., & Jensen, M. P. (2020). Longitudinal associations between physical activity, anxiety, and depression in adults with long-term physical disabilities. *Health Psychology, 39*, 529–538. https://doi.org/10.1037/hea0000848

Birk, J. L., Kronish, I. M., Moise, N., Falzon, L., Yoon, S., & Davidson, K. W. (2019). Depression and multimorbidity: Considering temporal characteristics of the associations between depression and multiple chronic diseases. *Health Psychology, 38*, 802–811. https://doi.org/10.1037/hea0000737

Chen, H.-M., Tsai, C.-M., Wu, Y.-C., Lin, K.-C., & Lin, C.-C. (2015). Randomised controlled trial on the effectiveness of home-based walking exercise on anxiety, depression and cancer-related symptoms in patients with lung cancer. *British Journal of Cancer, 112*, 438–445. https://doi.org/10.1038/bjc.2014.612

Choi, K. W., Chen, C.-Y., Stein, M. B., Klimentidis, Y. C., Wang, M.-J., Koenen, K. C., & Smoller, J. W. (2019). Assessment of bidirectional relationships between physical activity and depression among adults. *JAMA Psychiatry, 76*, 399–408. https://doi.org/10.1001/jamapsychiatry.2018.4175

Christofoletti, M., Sandreschi, P. F., Quadros, E. N., d'Orsi, E., Rech, C. R., Manta, S. W., & Benedetti, T. R. B. (2021). Physical activity and sedentary behavior as multimorbidity discriminators among elderly Brazilians: A cross-sectional study. *Sao Paulo Medical Journal Revista Paulista de Medicina, 139*, 372–379. https://doi.org/10.1590/1516-3180.2020.0504.R1.1802021

Chudasama, Y. V., Khunti, K. K., Zaccardi, F., Rowlands, A. V., Yates, T., Gillies, C. L., Davies, M. J., & Dhalwani, N. N. (2019). Physical activity, multimorbidity, and life expectancy: A UK biobank longitudinal study. *BMC Medicine, 17*, 108. https://doi.org/10.1186/s12916-019-1339-0

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2017). Combined associations of muscle-strengthening activities and accelerometer-assessed physical activity on multimorbidity: Findings from NHANES. *American Journal of Health Promotion, 31*, 274–277. https://doi.org/10.4278/ajhp.150520-QUAN-894

de Oliveira, L., da, S. S. C. B., Souza, E. C., Rodrigues, R. A. S., Fett, C. A., & Piva, A. B. (2019). The effects of physical activity on anxiety, depression, and quality of life in elderly people living in the community. *Trends Psychiatry Psychother, 41*, 36–42. https://doi.org/10.1590/2237-6089-2017-0129

Dekker, J., Buurman, B. M., & van der Leeden, M. (2019). Exercise in people with comorbidity or multimorbidity. Health Psychol. *Multimorbidity in Health Psychology and Behavioral Medicine Research, 38*, 822–830. https://doi.org/10.1037/hea0000750

Fessler, L., Maltagliati, S., Sieber, S., Cullati, S., Tessitore, E., Craviari, C., Luthy, C., Hanna, E., Meyer, P., Orsholits, D., Sarrazin, P., & Cheval, B. (2023). Physical activity matters for everyone's health, but individuals with multimorbidity benefit more. *Preventive Medicine, 34*, Article 102265. https://doi.org/10.1016/j.pmedr.2023.102265

Freedson, P. S., Melanson, E., & Sirard, J. (1998). Calibration of the computer science and applications, inc. accelerometer. *Medicine & Science in Sports & Exercise, 30*, 777–781. https://doi.org/10.1097/00005768-199805000-00021

Goodman, R. A., Ling, S. M., Briss, P. A., Parrish, R. G., Salive, M. E., & Finke, B. S. (2016). Multimorbidity patterns in the United States: Implications for research and clinical practice. *Journal of Gerontology Ser. A, 71*, 215–220. https://doi.org/10.1093/gerona/glv199

Gorzelitz, J., Peppard, P. E., Malecki, K., Gennuso, K., Nieto, F. J., & Cadmus-Bertram, L. (2018). Predictors of discordance in self-report versus device-measured physical activity measurement. *Annals of Epidemiology, 28*, 427–431. https://doi.org/10.1016/j.annepidem.2018.03.016

Gould, C., O'Hara, R., Goldstein, M., & Beaudreau, S. (2016). Multimorbidity is associated with anxiety in older adults in the Health and Retirement Study. *International Journal of Geriatric Psychiatry, 31*. https://doi.org/10.1002/gps.4532

Hsiao, C., Wen, C.-J., Yen, H.-Y., Hsueh, M.-C., & Liao, Y. (2022). Association between accelerometer-measured light-intensity physical activity and cognitive function in older adults. *The Journal of Nutrition, Health & Aging, 26*, 230–235. https://doi.org/10.1007/s12603-022-1749-0

Johnson, L. G., Butson, M. L., Polman, R. C., Raj, I. S., Borkoles, E., Scott, D., Aitken, D., & Jones, G. (2016). Light physical activity is positively associated with cognitive performance in older community dwelling adults. *Journal of Science and Medicine in Sport, 19*, 877–882. https://doi.org/10.1016/j.jsams.2016.02.002

Johnston, M. C., Crilly, M., Black, C., Prescott, G. J., & Mercer, S. W. (2019). Defining and measuring multimorbidity: A systematic review of systematic reviews. *The European Journal of Public Health, 29*, 182–189. https://doi.org/10.1093/eurpub/cky098

Khanolkar, A. R., Chaturvedi, N., Kuan, V., Davis, D., Hughes, A., Richards, M., Bann, D., & Patalay, P. (2021). Socioeconomic inequalities in prevalence and development of multimorbidity across adulthood: A longitudinal analysis of the mrc 1946 national survey of health and development in the UK. *PLoS Medicine, 18*, Article e1003775. https://doi.org/10.1371/journal.pmed.1003775

King, D. E., Xiang, J., & Pilkerton, C. S. (2018). Multimorbidity trends in United States adults, 1988-2014. *The Journal of the American Board of Family Medicine, 31*, 503–513. https://doi.org/10.3122/jabfm.2018.04.180008

Ku, P.-W., Steptoe, A., Liao, Y., Sun, W.-J., & Chen, L.-J. (2018). Prospective relationship between objectively measured light physical activity and depressive symptoms in later life. *International Journal of Geriatric Psychiatry, 33*, 58–65. https://doi.org/10.1002/gps.4672

Lehnert, T., Heider, D., Leicht, H., Heinrich, S., Corrieri, S., Luppa, M., Riedel-Heller, S., & König, H.-H. (2011). Review: Health care utilization and costs of elderly persons with multiple chronic conditions. *Medical Care Research and Review, 68*, 387–420. https://doi.org/10.1177/1077558711399580

Li, Y., Li, X., Yu, B., Li, J., He, R., Nima, Q., & Zhou, J. (2022). Association between chronic disease multimorbidity and leisure-time physical activity: Evidence from the China Multiethnic Cohort study. *Frontiers of Medicine, 9*, Article 874456. https://doi.org/10.3389/fmed.2022.874456

Loprinzi, P. D. (2016). Light-intensity physical activity and medical multimorbidity. *Southern Medical Journal, 109*, 174–177. https://doi.org/10.14423/SMJ.0000000000000426

Malecki, K. M. C., Nikodemova, M., Schultz, A. A., LeCaire, T. J., Bersch, A. J., Cadmus-Bertram, L., Engelman, C. D., Hagen, E., McCulley, L., Palta, M., Rodriguez, A., Sethi, A. K., Walsh, M. C., Nieto, F. J., & Peppard, P. E. (2022). The survey of the health of Wisconsin (SHOW) Program: An infrastructure for advancing population health. *Frontiers in Public Health, 10*, Article 818777. https://doi.org/10.3389/fpubh.2022.818777

Merikangas, K. R., Swendsen, J., Hickie, I. B., Cui, L., Shou, H., Merikangas, A. K., Zhang, J., Lamers, F., Crainiceanu, C., Volkow, N. D., & Zipunnikov, V. (2019). Real-time mobile monitoring of the dynamic associations among motor activity, energy, mood, and sleep in adults with bipolar disorder. *JAMA Psychiatry, 76*, 190–198. https://doi.org/10.1001/jamapsychiatry.2018.3546

Mochcovitch, M. D., Deslandes, A. C., Freire, R. C., Garcia, R. F., & Nardi, A. E. (2016). The effects of regular physical activity on anxiety symptoms in healthy older adults: A systematic review. *Revista Brasileira de Psiquiatria São Paulo, 38*, 255–261. https://doi.org/10.1590/1516-4446-2015-1893, 1999.

Muggah, E., Graves, E., Bennett, C., & Manuel, D. G. (2013). Ascertainment of chronic diseases using population health data: A comparison of health administrative data and patient self-report. *BMC Public Health, 13*, 16. https://doi.org/10.1186/1471-2458-13-16

Nieto, F. J., Peppard, P. E., Engelman, C. D., McElroy, J. A., Galvao, L. W., Friedman, E. M., Bersch, A. J., & Malecki, K. C. (2010). The survey of the health of Wisconsin (SHOW), a novel infrastructure for population health research: Rationale and methods. *BMC Public Health, 10*, 785. https://doi.org/10.1186/1471-2458-10-785

Norton, P. J. (2007). Depression anxiety and stress Scales (DASS-21): Psychometric analysis across four racial groups. *Anxiety, Stress & Coping, 20*, 253–265. https://doi.org/10.1080/10615800701309279

Pedersen, B. K., & Saltin, B. (2015). Exercise as medicine – evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scandinavian Journal of Medicine & Science in Sports, 25*, 1–72. https://doi.org/10.1111/sms.12581

Piercy, K. L., Troiano, R. P., Ballard, R. M., Carlson, S. A., Fulton, J. E., Galuska, D. A., George, S. M., & Olson, R. D. (2018). The physical activity guidelines for Americans. *JAMA, 320*, 2020–2028. https://doi.org/10.1001/jama.2018.14854

Rajoo, Y., Wong, J., Cooper, G., Raj, I. S., Castle, D. J., Chong, A. H., Green, J., & Kennedy, G. A. (2019). The relationship between physical activity levels and symptoms of depression, anxiety and stress in individuals with alopecia Areata. *BMC Psychol, 7*, 48. https://doi.org/10.1186/s40359-019-0324-x

Ramos-Sanchez, C. P., Schuch, F. B., Seedat, S., Louw, Q. A., Stubbs, B., Rosenbaum, S., Firth, J., van Winkel, R., & Vancampfort, D. (2021). The anxiolytic effects of exercise for people with anxiety and related disorders: An update of the available meta-analytic evidence. *Psychiatry Research, 302*, Article 114046. https://doi.org/10.1016/j.psychres.2021.114046

Read, J., Sharpe, L., Modini, M., & Dear, B. (2017). Multimorbidity and depression: A systematic review and meta-analysis. *Journal of Affective Disorders, 221*. https://doi.org/10.1016/j.jad.2017.06.009

Ribeiro, S. M. L., Malmstrom, T. K., Morley, J. E., & Miller, D. K. (2017). Fruit and vegetable intake, physical activity, and depressive symptoms in the African American Health (AAH) study. *Journal of Affective Disorders, 220*, 31–37. https://doi.org/10.1016/j.jad.2017.05.038

Roberts, K. C., Rao, D. P., Bennett, T. L., Loukine, L., & Jayaraman, G. C. (2015). Prevalence and patterns of chronic disease multimorbidity and associated determinants in Canada. *Health promotion and chronic disease prevention in Canada: research Policy and Practice, 35*, 87–94. https://doi.org/10.24095/hpcdp.35.6.01

Skou, S. T., Mair, F. S., Fortin, M., Guthrie, B., Nunes, B. P., Miranda, J. J., Boyd, C. M., Pati, S., Mtenga, S., & Smith, S. M. (2022). Multimorbidity. *Nature Reviews Disease Primers, 8*, 1–22. https://doi.org/10.1038/s41572-022-00376-4

Smith, L., Shin, J., Jacob, L., Schuch, F., Pizzol, D., López, S. G., Soysal, P., Tully, M., Butler, L., Barnett, Y., Veronese, N., Park, S., & Koyanagi, A. (2022). Physical multimorbidity predicts the onset and persistence of anxiety: A prospective analysis of the Irish longitudinal study on ageing. *Journal of Affective Disorders, 309*. https://doi.org/10.1016/j.jad.2022.04.022

Uemura, K., Makizako, H., Lee, S., Doi, T., Lee, S., Tsutsumimoto, K., & Shimada, H. (2018). Behavioral protective factors of increased depressive symptoms in community-dwelling older adults: A prospective cohort study. *International Journal of Geriatric Psychiatry, 33*, e234–e241. https://doi.org/10.1002/gps.4776

Vancampfort, D., Koyanagi, A., Ward, P. B., Rosenbaum, S., Schuch, F. B., Mugisha, J., Richards, J., Firth, J., & Stubbs, B. (2017). Chronic physical conditions, multimorbidity and physical activity across 46 low- and middle-income countries. *International Journal of Behavioral Nutrition and Physical Activity, 14*, 6. https://doi.org/10.1186/s12966-017-0463-5

Vogeli, C., Shields, A. E., Lee, T. A., Gibson, T. B., Marder, W. D., Weiss, K. B., & Blumenthal, D. (2007). Multiple chronic conditions: Prevalence, health consequences, and implications for quality, care management, and costs. *Journal of General Internal Medicine, 22*(Suppl 3), 391–395. https://doi.org/10.1007/s11606-007-0322-1

Wipfli, B. M., Rethorst, C. D., & Landers, D. M. (2008). The anxiolytic effects of exercise: A meta-analysis of randomized trials and dose-response analysis. *Journal of Sport & Exercise Psychology, 30*, 392–410. https://doi.org/10.1123/jsep.30.4.392

Yasunaga, A., Shibata, A., Ishii, K., Koohsari, M. J., & Oka, K. (2018). Cross-sectional associations of sedentary behaviour and physical activity on depression in Japanese older adults: An isotemporal substitution approach. *BMJ Open, 8*, Article e022282. https://doi.org/10.1136/bmjopen-2018-022282

Zhang, L., Sun, F., Li, Y., Tang, Z., & Ma, L. (2021). Multimorbidity in community-dwelling older adults in Beijing: prevalence and trends, 2004-2017. *The Journal of Nutrition, Health & Aging, 25*, 116–119. https://doi.org/10.1007/s12603-020-1467-4

Zhao, G., Lu, Z., Sun, Y., Kang, Z., Feng, X., Liao, Y., Sun, J., Zhang, Y., Huang, Y., & Yue, W. (2023). Dissecting the causal association between social or physical inactivity and depression: A bidirectional two-sample mendelian randomization study. *Translational Psychiatry, 13*, 194. https://doi.org/10.1038/s41398-023-02492-5