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A cluster analysis of device-measured physical activity behaviours and the association with chronic conditions, multi-morbidity and healthcare utilisation in adults aged 45 years and older

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ABSTRACT

Most adults do not meet physical activity guidelines with negative implications for health. The aim of this study was to profile adults using multiple physical activity behaviours and to investigate associations with chronic conditions, multi-morbidity and healthcare utilisation. The study used data generated from a sample of adults aged 45 years and older (N = 485), recruited to the Move for Life randomised control trial. Participants wore an accelerometer for eight consecutive days. Hierarchical cluster analysis was conducted using the variables: moderate to vigorous intensity physical activity, light intensity physical activity, step count, waking sedentary time, standing time and bed hours. Descriptive statistics were used to investigate associations with self-reported number of chronic illnesses, multi-morbidity and healthcare utilisation. Four distinct physical activity behaviour profiles were identified: inactive-sedentary (n = 50, 10.3%), low activity (n = 295, 60.8%), active (n = 111, 22.9%) and very active (n = 29, 6%). The inactive-sedentary cluster had the highest prevalence of chronic illnesses, in particular, mental illness (p = 0.006) and chronic lung disease (p = 0.032), as well as multi-morbidity, complex multi-morbidity and healthcare utilisation. The prevalence of any practice nurse visit (p = 0.033), outpatient attendances (p = 0.04) and hospital admission (p = 0.034) were higher in less active clusters. The results have provided an insight into how physical activity behaviour is associated with chronic illness and healthcare utilisation. A group within the group has been identified that is more likely to be unwell. Provisions need to be made to reduce barriers for participation in physical activity for adults with complex multi-morbidity and very low physical activity.

1. Introduction

Non communicable diseases (NCD), also termed chronic conditions (WHO, 2018), account for 72% of all global deaths (Hay and Collaborators GCoD., 2017). In Ireland, NCDs, mainly cancer, circulatory and respiratory disease account for 75% of total deaths (Central Statistics Office, 2019), are extremely costly to population health (Ding et al., 2016); yet are largely preventable. One of the main contributors to NCDs and premature mortality worldwide is physical inactivity (Lee et al., 2012); thus, addressing population inactivity levels is a primary target of the World Health Organisation (WHO) (WHO, 2016). As adults get older, they acquire more chronic illnesses (Hung et al., 2011), but they also engage in less physical activity (Fishman et al., 2016 Jul).

Multi-morbidity, the co-existence of two or more chronic illnesses (Tinetti et al., 2012), is present in 70% of people aged 75 years and over (Centre for Medicare and Medicaid Services) and is associated with disability and higher healthcare utilisation (Cassell et al., 2018). Greater disability and mortality are associated with complex multi-morbidity

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(Storeng et al., 2020), defined as having three or more chronic illnesses across three different bodily systems (Harrison et al., 2014). The prevalence of multi-morbidity is expected to expand over the next 20 years, and, consequently, a re-focus in health strategy, prioritising prevention among middle-aged and older adults, is appropriate (Kingston et al., 2018). Regular physical activity helps to reduce premature mortality and contributes to primary prevention (Lear et al., 2017) and treatment of chronic illness (Pedersen and Saltin, 2015) and multi-morbidity (Duggal et al., 2019). Researchers have recommended more studies investigating the association between physical activity and healthcare utilisation (Sari, 2011). The authors are not aware of research reporting device-measured physical activity behaviour and its association with healthcare utilisation.

Physical activity guidelines consistently state that 150 min of moderate intensity physical activity or 75 min of vigorous physical activity per week is the minimum requirement for health (Officers, 2011; Piercy et al., 2018; World Health Organisation. WHO, 2020). The 2020 WHO guidelines provide recommendations for adults with chronic illness, reflecting the growing evidence for the role of physical activity in health (World Health Organisation. WHO, 2020); they emphasise that any physical activity is better than none, and have a strong focus on sedentary behaviour (Ding et al., 2020). Uncertainty remains around the health benefit of physical activity at different intensities and volumes (Bull et al., 2020), but it seems that even small increases in physical activity extend important health benefits among middle aged and older adults (Macera et al., 2017). Recently, health benefits of light intensity physical activity (LiPA), independent of moderate-vigorous physical activity (MVPA), have been reported (Amagasa et al., 2018; Ku et al., 2020). Sedentary behaviour involves prolonged bouts of sitting and has negative health sequelae. It is possible to be physically active and still accumulate unhealthy levels of sedentary time (Dunstan et al., 2005). Accordingly, sedentary behaviour has been identified as a risk factor for mortality and incidence of chronic illness, that is independent of physical activity (Biswas et al., 2015), with a strong message emerging – move more and sit less (Ekelund et al., 2019). Investigating the full continuum of movement, from sedentary behaviour through to MVPA, and its association with health and healthcare utilisation is the focus of this study.

Device-measured physical activity and sedentary behaviour has the advantage of overcoming recall bias as well as providing accurate means of deducing various intensities and volumes (Prince et al., 2019). Sophisticated devices, with the application of intensity thresholds, now have the ability to measure all habitual activity behaviours on intensity continuum (i.e., sitting/lying time, standing time and intensity). Cluster analysis is a multivariate statistical method which aims to group participants so that participants in the same group or cluster are more similar to each other (across multiple physical activity and sedentary behaviours) than they are to those in other clusters; it has been successfully used in middle-aged and older adults (Geidl et al., 2019). Exploring how physical activity and sedentary behaviour occur in populations and how they relate to chronic illnesses and healthcare utilisation could provide important new knowledge for intervention design and health policy. The aim of this study was to investigate how physical activity and sedentary behaviour cluster together and to explore associations between clusters and chronic illness, multi-morbidity and healthcare utilisation in older adults.

2. Method

2.1. Design and participants

This study used baseline data from the Move for Life feasibility randomised control trial which was conducted in Ireland's mid-west region, in counties Limerick and Clare. Move For Life was developed to test a community-based intervention to encourage inactive adults to get more active; details of the intervention design and study protocol are provided elsewhere (O'Regan et al., 2019).

The study met the institution's guidelines for protection of participants' privacy and safety, and full ethical approval was granted by the University of Limerick Education and Health Sciences research ethics committee (EHS_2018_02_15). Participants were adults aged 45 years and older.

2.2. Data collection

Baseline data collection events, involving physical function tests, fitting of accelerometers and questionnaires were held across eight sports and community centres during May to September 2018. Participants completed a two-item questionnaire on the number of days they spent engaged in at least 30 min of MVPA and the number of hours spent in MVPA in a typical week (Murphy et al., 2015). Accelerometers were given to both active and inactive people.

2.3. Habitual physical activity behaviour measurements

Six measures were selected because of reported associations for each one with health outcomes; lower mortality is associated with: higher step count (Saint-Maurice et al., 2020); higher LiPA (Amagasa et al., 2018); higher standing time (Katzmarzyk, 2014); and higher MVPA (Hupin et al., 2015); whereas sleep times that are either longer or shorter than optimal (Silva et al., 2016), and higher sedentary time (Biswas et al., 2015) are associated with adverse health outcomes.

Physical activity behaviours were assessed using the activPAL 3 micro accelerometer. The device was fitted to the anterior aspect of the right thigh using a nitrile sleeve and waterproof Tegaderm dressing. Participants were instructed to wear the monitor for 24 h/day, for eight consecutive days and were advised to remove the device *only* if they were going to be submerged in water for a prolonged period.

The output files from the activPAL 3 micro were examined to calculate daily waking sedentary time, standing time, LiPA, MVPA, step-count and bed hours. Sedentary time and standing time were calculated using the postural function of the activPAL 3 micro. Bed hours were calculated by first identifying a time that the participants had not yet woken (05:00:00 was used). The first non-sedentary epoch after 5:00:00 was identified as rise time. The number of bed hours was determined by visually scanning the data to identify the last registered non-sedentary epoch of the day, which was followed by a long uninterrupted sedentary period (>3 h) (Harrington et al., 2011; Dowd et al., 2012). Bed hours were then subtracted from total daily sedentary time, to provide sedentary time during the day. MVPA was calculated using a previously developed and validated count-to-activity threshold (8873 counts.15sec^{-1}) developed from the sum of the vector magnitude for each 15 s period (Harrington et al., 2011; Powell et al., 2017). The time spent in MVPA was then summed over the entire 24-hour measurement period. LiPA was calculated as 24 h - [sedentary time + standing time + MVPA time] (Dowd et al., 2014).

Participants were required to provide at least four valid days of accelerometer recording (3weekdaysand1weekendday); a valid day was classified as ≥ 10 h of recording during waking hours (Edwardson et al., 2017). All monitor outputs were examined for non-wear time, which was defined as a period with ≥ 60 min of consecutive zero accelerometer activity counts during waking hours.

2.4. Healthcare and healthcare utilisation measures

Participants were requested to complete a series of questionnaires, including a list of common chronic illnesses, using International Classification of Diseases Revision 10 nomenclature, where they could tick the box to indicate that they had been diagnosed with a particular illness. The number of chronic illnesses was counted, and participants categorised to multi-morbidity if they reported two or more chronic illnesses. The number of bodily systems affected was also counted and participants categorised to complex multi-morbidity if three or more bodily systems were affected.

Participants were asked to record if, over the previous six months, they had visited their GP, practice nurse, other health service, or if they had a hospital admission. The questions were based on a largescale national study of adults over 50, The Irish Longitudinal study on Ageing (TILDA) (TILDA).

Height was measured to the nearest 0.25 cm, using a portable stadiometer (Seca model 214; Seca Ltd, Birmingham, UK) and body mass was measured to the nearest 0.1 kg using a portable electronic scale (Seca model 770; Seca Ltd, Birmingham, UK). Body mass index (BMI) was recorded using the standard formula (Kg/m^{-2}).

2.5. Socio-demographics

Socio-demographic characteristics collected included: age, gender, living alone or with a partner, level of education attainment, having private health insurance, employment status and having a General Medical Services (medical) card. In Ireland, medical cards are granted to people if their individual or household annual income is below a threshold. Higher income thresholds are used for those aged over 70. Medical card holders do not pay for GP consultations and for most medications and constitute approximately 53% of the TILDA sample (TILDA, 2018).

2.6. Statistical analysis

Numeric variables are summarised using mean (standard deviation) for normally distributed variables and median (interquartile range) for skewed distributions. Categorical variables are summarised using counts and percentages. An exploratory hierarchical cluster analysis was carried out using six physical activity variables, all measured on an interval scale: average daily hours in bed, average daily waking sedentary hours, average daily standing hours, average daily LiPA hours, average daily MVPA minutes and average daily step count.

The clusters were formed starting with each observation as their own subgroup and at every step joining the two closest subgroups together until only one group remained. The distance measure used was the squared Euclidian distance and the method was between-groups linkage. The number of clusters was not specified in advance and a range of cluster solutions was explored. The final number of clusters was decided using visual inspection of the dendrogram and by comparing silhouette plots and average silhouette score across cluster solutions. Silhouette scores range from −1 to + 1 with higher average scores indicating more cohesive, well-separated clusters (Rousseeuw, 1987).

Cluster membership for the final cluster solution was associated with socio-demographic variables, self-reported prevalence of chronic diseases, multi-morbidity, complex multi-morbidity, BMI category and healthcare utilisation. A chi-square test was used to test for associations between categorical variables. A 5% significance level was used for all tests. Logistic regression models were fitted for the association between binary outcomes and physical activity cluster, adjusting for age, gender and highest level of education. Odds ratios with 95% confidence intervals (CI) are presented. All statistical analysis was carried out using SPSS version 26.

3. Results

3.1. Study population characteristics

A total of 531 subjects were given accelerometers at baseline testing for Move for Life. Of these, 46 were disqualified for not fulfilling the wearing criteria: insufficient number of valid days worn (n = 26); device not worn (n = 17); and device malfunction (n = 3). Valid accelerometer data were obtained from 485 participants, all of whom wore the activPAL for at least 10 h per day; the majority (n = 442) did so for at least six days.

Table 1 provides demographic data and Table 2 provides a detailed description of the morbidity and healthcare utilisation of the sample. Of the 485 participants, 381 (78.6%) were female and 260 (54%) were insufficiently active according to pre-test criteria. The mean age of the study population was 62.3 years (SD = 8.6), and 105 (22%) were aged 70 years or older. One hundred and fifty-four (32.7%) had a medical card, 382 (80.6%) had private medical insurance and 324 (68.4%) were living with a spouse or partner. Three hundred and ninety-two (81.1%) were overweight or obese. Three hundred and sixty-nine (76%) had at least one chronic condition; the median number of chronic conditions was two; and 251 (51.8%) had multi-morbidity. The most common chronic conditions reported were high cholesterol (n = 175, 36.1%), hypertension (n = 153, 31.5%) and arthritis (n = 150, 30.9%). The majority (n = 367, 81.6%) had attended their general practitioner in the previous six months and 137 (n = 32.8%) had attended the practice nurse; 35 (8.1%) had attended the emergency department.

3.2. Physical activity clusters

Four clusters were identified and were descriptively labelled according to their relative traits. Full details are provided in Table 3. The activity clusters were defined as follows:

1) Inactive-sedentary cluster, (n = 50 (10.3%)): least favourable profile characterised by long bed hours, high waking sedentary time, low levels of LiPA, MVPA and step count.
2) Low activity cluster, (n = 295 (60.8%)): characterized by lower bed hours, lower waking sedentary waking time, higher levels of standing, LiPA, MVPA and step count compared to the first cluster.
3) Active cluster, (n = 111 (22.9%)): characterised by less bed hours and more favourable levels of standing, LiPA, MVPA and step count.
4) Very active cluster (n = 29 (6%)) most favourable activity profiles characterised by low waking sedentary time and high standing time, LiPA, MVPA and step count.

3.3. Cluster socio-demographics

Table 4 outlines the socio-demographic characteristics of each cluster. The two least active clusters had higher proportions of subjects aged

Table 1
Socio-demographic characteristics (n = 485).

Characteristic	n (%)
Age group	
45–59 years	192 (39.7%)
60–69 years	187 (38.6%)
≥70 years	105 (21.7%)
Gender	
Male	104 (21.4%)
Female	381 (78.6%)
Living with a partner	
Yes	324 (68.4%)
No	150 (31.6%)
Highest level of education	
Primary/lower secondary	102 (21.6%)
Secondary/non-tertiary	132 (28%)
Tertiary – non degree	117 (24.8%)
Tertiary – degree	121 (25.6%)
Work status	
Employed	194 (40.9%)
Retired	195 (41.1%)
Other	85 (17.9%)
Private health insurance	
Yes	382 (80.6%)
No	92 (19.4%)
Medical card	
Yes	154 (32.7%)
No	317 (67.3%)

Table 2
Health and healthcare utilisation (n = 485).

Disease prevalence	
Condition	n (%)
High Cholesterol	175 (36.1%)
Hypertension	153 (31.5%)
Arthritis	150 (30.9%)
Osteoporosis	94 (19.4%)
Circulatory conditions[1]	79 (16.3%)
Mental illness	55 (11.3%)
Asthma	43 (8.9%)
Diabetes	34 (7%)
Cancer	31 (6.4%)
Chronic lung conditions	21 (4.3%)
Body Mass Index	
Underweight/NormalOverweightObese	90 (18.9%)184 (38.7%)202 (42.4%)
Healthcare utilisation	
Any visit to the GP in the previous 6 months	367 (81.6%)
Any visit to the practice nurse in the previous 6 months	137 (32.8%)
Any visit to other services in the previous 6 months	149 (35.5%)
Any visit to outpatient services in the previous 6 months	118 (27.1%)
Any visit to the Emergency Department in previous 6 months	35 (8.1%)
Any hospital admission in the previous 6 months	36 (8.3%)

[1]Includes angina, heart attack, stroke, mini stroke/TIA, congestive heart failure, abnormal heart rhythm, heart murmur, other heart problems.

Table 3
Physical activity cluster profiles (n = 485).

Physical activity variable	Inactive-sedentary (n = 50, 10.3%) Median (Q1, Q3)	Low activity (n = 295, 60.8%) Median (Q1, Q3)	Active (n = 111, 22.9%) Median (Q1, Q3)	Very active (n = 29, 6%) Median (Q1, Q3)	Total (n = 485) Median (Q1, Q3)
Moderate-vigorous physical activity (mins/day)	7.7 (4.2, 14.6)	25.5 (19.1, 35.5)	52.2 (43.3, 64.9)	94.4 (61.9, 108)	30.1 (19.2, 48.0)
Standing time (hrs/day	3.2 (2.5, 4.1)	4.6 (3.6, 5.4)	5.2 (4.3, 6.0)	5.1 (4.3, 6.1)	4.6 (3.6, 5.5)
Bed hours (hrs/day)	8.9 (8.1, 9.8)	8.4 (7.8, 9.0)	8.1 (7.5, 8.6)	8.0 (7.5, 8.6)	8.3 (7.7, 8.0)
Step count (steps/day	4328 (3044, 5231)	8158 (6996, 9621)	12,681 (12144, 13588)	17,982 (16386, 20284)	9108 (6954, 11964)
Sedentary Waking hours (hrs/day)	10.7 (9.9, 11.8)	8.4 (9.4, 10.4)	8.2 (7.2, 9.0)	7.3 (6.5, 8.4)	9.1 (7.0, 10.4)
Light physical activity (hrs/day)	0.8 (0.6, 0.9)	1.3 (1.1, 1.6)	1.7 (1.5, 2.0)	2.2 (1.8, 2.5)	1.4 (1.1, 1.7)

70 years and older and were more likely not to be living with a partner. A significant association ($p < 0.001$) was found between cluster membership and having a medical card, with higher proportions having a medical card in the less active clusters. A significant association ($p = 0.02$) was also found between cluster membership and having private health insurance, with the lowest proportion having private health insurance in the least active cluster.

Table 4
Socio-demographic variables by cluster (n = 485)

Socio-demographic variable	Inactive-sedentary (n = 50)	Low activity (n = 295)	Active (n = 111)	Very active (n = 29)	P-value
Age group					0.69
45–59 years	16 (32%)	117 (39.8%)	46 (41.4%)	13 (44.8%)	
60–69 years	22 (44%)	108 (36.7%)	45 (40.5%)	12 (41.4%)	
≥ 70 years	12 (24%)	69 (23.5%)	20 (18%)	4 (13.8%)	
Gender					0.17
Male	14 (28%)	57 (19.3%)	23 (20.7%)	10 (34.5%)	
Female	36 (72%)	238 (80.7%)	88 (79.3%)	19 (65.5%)	
Living with a partner					0.35
Yes	29 (60.4%)	195 (67.2%)	79 (73.8%)	21 (72.4%)	
No	19 (39.6%)	95 (32.8%)	28 (26.2%)	8 (27.6%)	
Highest level of education					0.70
Primary/lower second	15 (31.3%)	56 (19.4%)	22 (20.6%)	9 (31%)	
Secondary/non-tertiary	12 (25%)	81 (28.1%)	30 (28%)	9 (31%)	
Tertiary – non degree	12 (25%	73 (25.3%)	26 (24.3%)	6 (20.7%)	
Tertiary – degree	9 (18.8%)	78 (27.1%)	29 (27.1%)	5 (17.2%)	
Work status					0.08
Employed	10 (20.8%)	122 (42.1%)	50 (46.7%)	12 (41.4%)	
Retired	25 (52.1%)	118 (40.7%)	42 (39.3%)	10 (34.5%)	
Other	13 (27.1%)	50 (17.2%)	15 (14%)	7 (24.1%)	
Private health insurance					0.02
Yes	31 (64.6%)	237 (81.7%)	92 (86%)	22 (75.9%)	
No	17 (35.4%)	53 (18.3%)	15 (14%)	7 (24.1%)	
Medical card					<0.001
Yes	26 (54.2%)	99 (34.4%)	23 (21.7%)	6 (20.7%)	
No	22 (45.8%)	189 (65.6%)	83 (78.3%)	23 (79.3%)	

3.4. Cluster health and health service utilisation

The inactive-sedentary group had the highest prevalence of each chronic illness except for osteoporosis and cancer (Table 5). Significant associations with cluster membership were found with chronic lung disease ($p = 0.03$) with the highest prevalence in the inactive-sedentary group and none in the very active group. Significant associations were also found with mental illness ($p = 0.006$) and BMI category ($p < 0.001$). Almost 70% of the inactive-sedentary group were obese and over a quarter reported having a mental illness (Fig. 1). The association between cluster membership and mental illness and obesity was significant after adjusting for age, gender, and highest level of education in a multivariable model (Table 6).

Complex multi-morbidity was significantly associated with cluster membership ($p < 0.001$) with over a third of the inactive-sedentary group having complex multi-morbidity compared to 3% of the very active group. All healthcare utilisation reported was highest in the inactive-sedentary group, with lower proportions reporting utilisation in more active groups. Significant associations with cluster membership were seen with any nurse visit ($p = 0.03$), any outpatient visit ($p = 0.04$) and any hospital admission ($p = 0.04$), in the previous six months. The association between cluster membership and complex multi-morbidity and any nurse visit in the previous six months was significant after

Table 5
Health and healthcare utilisation by cluster (n = 485)

	Inactive-Sedentary (n = 50)	Low activity (n = 295)	Active (n = 111)	Very active (n = 29)	P-value
Condition prevalence					
Condition					
High Cholesterol	20 (40%)	104 (35.3%)	43 (38.7%)	8 (27.6%)	0.64
Hypertension	18 (36%)	100 (33.9%)	29 (26.1%)	6 (20.7%)	0.23
Arthritis	22 (44%)	92 (31.2%)	31 (27.9%)	5 (17.2%)	0.07
Osteoporosis	5 (10%)	58 (19.7%)	27 (24.3%)	4 (13.8%)	0.16
Circulatory conditions[1]	13 (26%)	48 (16.3%)	16 (14.4%)	2 (6.9%)	0.13
Mental illness	13 (26%)	28 (9.5%)	10 (9%)	4 (13.8%)	0.006
Asthma	7 (14%)	26 (8.8%)	8 (7.2%)	2 (6.9%)	0.54
Diabetes	5 (10%)	23 (7.8%)	4 (3.6%)	2 (6.9%)	0.40
Cancer	3 (6%)	17 (5.8%)	9 (8.1%)	2 (6.9%)	0.86
Chronic lung conditions	6 (12%)	11 (3.7%)	4 (3.6%)	0 (0%)	0.03
Multi-morbidity	31 (62%)	149 (50.5%)	59 (53.8%)	11 (37.9%)	0.08
Complex multi-morbidity	17 (34%)	39 (13.2%)	12 (10.8%)	1 (3.4%)	<0.001
Body Mass Index					
Underweight/NormalOverweightObese	4 (8.3%)11 (22.9%)33 (68.8%)	48 (16.5%)119 (40.9%)124 (42.6%)	30 (27.8%)41 (38%)37 (34.3%)	8 (27.6%)13 (44.8%)8 (27.6%)	<0.001
Healthcare utilisation in the previous 6 months					
Any visit to the GP	40 (90.9%)	224 (80.9%)	82 (81.2%)	21 (75%)	0.33
Any visit to the practice nurse	21 (52.5%)	82 (32.3%)	27 (27.6%)	7 (26.9%)	0.03
Any visit to other health srvices	19 (43.2%)	89 (34.9%)	35 (36.8%)	6 (23.1%)	0.39
Any visit to outpatient services	18 (41.9%)	71 (26.7%)	26 (26.3%)	3 (11.1%)	0.04
Any visit to the Emergency Department	5 (11.6%)	23 (8.7%)	5 (5.2%)	2 (7.7%)	0.59
Any hospital admission	8 (18.2%)	19 (7.2%)	9 (9.2%)	0 (0%)	0.04

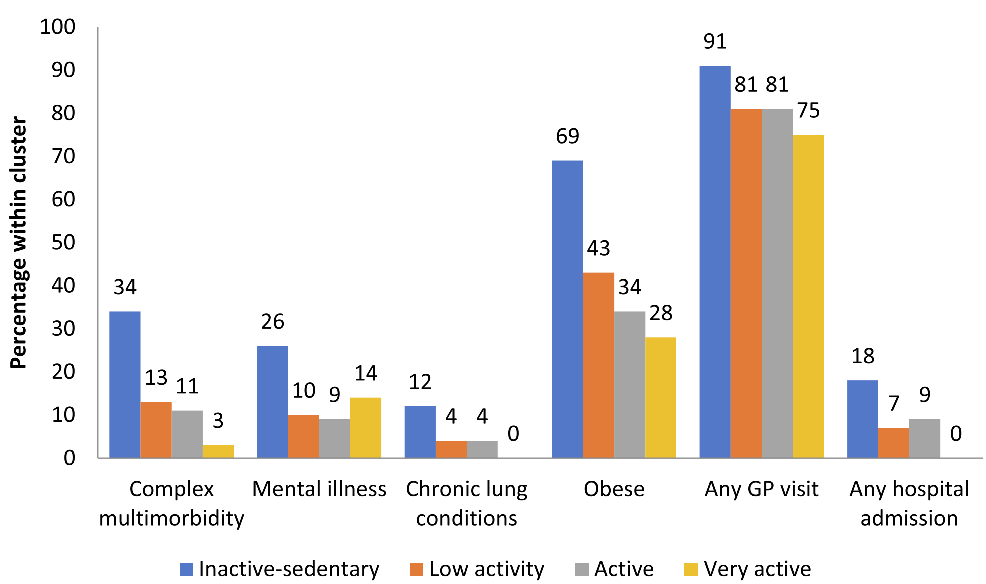

Fig. 1. Health outcomes by cluster.

adjusting for age, gender and highest level of education in a multivariable model (Table 6).

4. Discussion

4.1. Summary of findings

This is the first study that uses cluster analysis to group middle aged and older adults by device-measured physical activity behaviours and to compare chronic illness, multi-morbidity, complex multi-morbidity and health care utilisation across the clusters. Significant differences in the prevalence of chronic lung disease, mental illness, BMI category, complex multi-morbidity levels, and primary and secondary health care utilisation, were observed across the clusters. Cluster analysis has facilitated the identification of a highly inactive and sedentary group that has significant levels of morbidity and healthcare need.

4.2. Comparison to research

The study population was predominantly female and had a high proportion (46%) were physically active, according to pre-test questionnaires. Challenges recruiting men to physical activity research have been reported (Chinn et al., 2006). The high proportion of participants that were already physically active is consistent with research reporting strong selection bias towards more active people being recruited to physical activity trials (Harris et al., 2008; Halbert et al., 1999). Active

Table 6
Logistic regression of outcomes.

Outcome	Odds ratio for physical activity cluster (95% CI)[1]		p-value
Mental illness	Inactive-sedentary	2.96 (0.82, 10.68)	0.002
	Low activity	0.64 (0.20, 2.07)	
	Active	0.66 (0.18, 2.36)	
	Very active	Reference	
Obesity	Inactive-sedentary	6.40 (2.27, 18.05)	<0.001
	Low activity	2.04 (0.86, 4.81)	
	Active	1.51 (0.60, 3.77)	
	Very active	Reference	
Complex multi-morbidity	Inactive-sedentary	14.58 (1.76, 120.73)	0.001
	Low activity	3.92 (0.51, 30.46)	
	Active	3.61 (0.44, 29.65)	
	Very active	Reference	
Any nurse visit in previous 6 months	Inactive-sedentary	3.10 (1.05, 9.18)	0.046
	Low activity	1.33 (0.53, 3.33)	
	Active	1.06 (0.40, 2.84)	
	Very active	Reference	

[1]Adjusted for age, gender and highest level of education.

adults were encouraged to participate in Move for Life as a means of encouraging less active and more reluctant partners and friends to attend with them. The mean age of the study population was 62.3 years, with 22% aged 70 years or older. Age was not significantly associated with cluster, but the percentage of adults aged 70 years and over in the inactive-sedentary group (24%) far exceeded that in the very active group (13.8%).

TILDA reported that 44% of the population over 50 were overweight and 34% were obese (Fifty Plus in Ireland, 2011), whereas the prevalence of obesity in our study was higher (42%). This may be that participants viewed the Move for Life trial as an intervention to lose weight; physical gains, in this case weight loss, are the major motivating factor for recruitment to physical activity interventions (Grant et al., 2017). BMI category was significantly associated with cluster, after adjusting for age, gender, and highest level of education, with highest obesity in the inactive-sedentary group. Obesity–related chronic illness is expected to rise further (Seidell and Halberstadt, 2015).

Most participants (71.1%) were categorised to inactive-sedentary or low activity groups, and the participants in the two more active clusters achieved minimum physical activity guidelines (World Health Organisation. WHO, 2020). This is comparable to the national profile; 39% of people aged over 55 years are physically inactive and inactivity increases with age (Murtagh et al., 2015). Notably, the median time in spent MVPA and step counts per day for the very active cluster were almost an hour and a half and 18,000 respectively. The active cluster also had higher than expected median MVPA and step counts. Some participants may have been already highly active and may have viewed Move for Life as a new challenge. Furthermore, subjects sometimes change their behaviour when they know they are the subject of an experiment – the so-called Hawthorne effect (Levitt and List, 2011); this phenomenon is strongest during the first few weeks of a study- at baseline testing (Tiefenbeck, 2016).

This study reports a significant association between private health insurance and physical activity cluster; the cluster profile with the lowest proportion of private health insurance was the least active-sedentary group. TILDA reported that 35% of participants had private health insurance, compared to 80.7% of Move for Life participants; and that 38% were eligible for a GMS card, similar to 32.7% of study participants (TILDA, 2013). TILDA reported that self-reported physical activity levels are highest among wealthier adults (Fifty Plus in Ireland, 2011), consistent with international findings that report lower physical activity levels among more socially disadvantaged groups (Craike et al., 2019).

The inactive-sedentary cluster had the highest healthcare utilisation, with statistical associations for hospital admissions and practice nurse visits; number of practice nurse visits was higher among the least active-sedentary group after adjusting for gender, aged and highest level of education. It may be that this group, with higher levels of complex morbidity are scheduled for more health checks; people with chronic illnesses attend their practice more often if a standardised protocol for their care is in place, and practice nurses deliver these types of scheduled consultations (O'Connor et al., 2019). Highest prevalence of mental health conditions was in the inactive-sedentary cluster (26%) and the prevalence of a mental health condition decreased as clusters became more active until the most active cluster where the prevalence peaked again (13.8%). Research has demonstrated that higher levels of physical activity are associated with better mental health and that the relationship is bi-directional (Steinmo et al., 2014).

This study reported an association between 'complex-multi-morbidity' and device-measured sedentary-low active behaviour. Similarly, participants in TILDA that had four or more chronic conditions were more likely to self-report being sedentary (Kandola et al., 2020). Complex multi-morbidity, which incorporates number of body systems affected as well as number of chronic illnesses accrued, may be a stronger indicator of the patient complexity and healthcare need (Wallace et al., 2015). The English Longitudinal Study on Ageing noted an inverse dose response between levels of self-reported physical activity and development of multi-morbidity (Dhalwani et al., 2016).

4.3. Strengths and limitations

A key contribution of this study is the objective assessment of habitual physical activity behaviour. The activPAL 3 micro has previously been deemed the gold-standard for the measurement of sedentary time (Kozey-Keadle et al., 2011). In addition, an age-specific previously developed and validated count-to-activity threshold for the determination of MVPA using the activPAL 3 micro was used in the current study (Powell et al., 2017). This enabled the accurate determination of sedentary time, standing time, LiPA and MVPA from just one device. An added strength is that the device was used to derive a measure of bed-hours, which acted as a surrogate measure for sleep time. A limitation is the convenience sample, comprised of Move for Life participants who were volunteers. The low proportion of medical card holders and the high proportion of female participants in the study population compared to the general population, are possibly reflective of this. Data on annual income was not collected and private health insurance and having a GMS card were used as surrogates for socio-economic status. The authors cannot out-rule the potential for reverse causality; for example, cancer related fatigue might cause inactivity; or obesity might result in inactivity. Finally, the Hawthorne effect (tendency of participants to alter behaviour), in this case through increased physical activity, has been reported and is thought to be stronger during the first few weeks of the study, coinciding with the timeframe of data collection for Move for Life.

5. Conclusion

The use of cluster analysis of device-measured physical activity behaviour has produced four distinct cluster profiles, providing new insight into physical activity behaviour and its association with morbidity and healthcare utilisation. The least active and sedentary cluster profile has a significantly higher amount chronic illness and complex multi-morbidity, as well as higher healthcare utilisation.

CRediT authorship contribution statement

Andrew O'Regan: Conceptualization, Data curation, Methodology, Writing – original draft. **Ailish Hannigan:** Methodology, Supervision, Writing – original draft. **Liam Glynn:** Conceptualization, Supervision, Writing – review & editing. **Enrique Garcia Bengoechea:** Conceptualization, Writing – review & editing. **Alan Donnelly:** Methodology, Writing – review & editing. **Grainne Hayes:** Data curation, Writing – review & editing. **Andrew W. Murphy:** Writing – review & editing. **Amanda M. Clifford:** Writing – review & editing. **Stephen Gallagher:** Writing – review & editing. **Catherine B. Woods:** Conceptualization, Supervision, Writing – review & editing.

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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Ethics

Research Ethics Committee of University of Limerick (Registration No. 2018_02_15_EHS).

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