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Full-length Article

Association of Weight Status and Waist Circumference with Physical Activity in people with Schizophrenia Spectrum Disorders and healthy controls

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ABSTRACT

Background: Individuals with Schizophrenia Spectrum Disorders (SSD) often suffer from obesity and do limited Physical Activity (PA). PA has many beneficial effects on a variety of somatic and mental variables and it should be strengthened among people with mental disorders. The relationship between Body Mass Index (BMI), Waist Circumference (WC), and PA in this population is poorly understood, with a lack of precise PA assessment. This study investigates the association between BMI, WC, weight, and PA in individuals with SSD and controls using accelerometers.
Methods: One hundred twenty-six patients with SSD (residents and outpatients) and 110 sex- and age-matched controls were enrolled. Clinical, sociodemographic, and quality-of-life data were collected. PA was measured with a tri-axial ActiGraph GT9X and quantified by Vector Magnitude (VM). Relationships between PA and BMI, WC, and weight changes were analysed using linear regression models.
Results: Patients were more likely to be unmarried, unemployed, and less educated compared to controls ($p < 0.001$). Residents had more medical comorbidities ($p = 0.001$), while outpatients had higher BMI, weight, and WC ($p < 0.001$). Residents reported more severe psychopathology, lower functioning, and greater use of psychopharmacological medications ($p < 0.001$). Higher PA levels were not significantly associated with lower BMI, WC, or weight. Although not statistically significant, increased PA showed a trend towards lower obesity risk.
Conclusions: Sociodemographic, medical, and clinical characteristics of individuals with SSD define vulnerability factors that can inform tailored interventions to improve PA.

1. Introduction

Schizophrenia Spectrum Disorders (SSD) exert a profound impact on affected individuals, extending beyond traditionally recognised psychiatric symptoms. An increasingly acknowledged concern is the high prevalence of obesity and overweight in this clinical group, significantly exceeding that of the general population (Berti et al., 2018; Holt et al., 2018).

Abbreviations: AP, antipsychotic; APA, American Psychiatric Association; BMI, body mass Index; BNSS, Brief Negative Symptom Scale; BPRS, Brief Psychiatric Rating Scale; DMH, Department of Mental Health; DSM-5, Diagnostic and Statistical Manual of Mental Disorders 5th Edition; IRCCS, Istituto di Ricovero e Cura a Carattere Scientifico (eng., clinical research centre); MMSE, Mini-Mental State Examination; PA, physical activity; QoL, quality of life; RF, residential facility; SLOF, Specific Levels of Functioning Scale; SSD, Schizophrenia Spectrum Disorders; WC, Waist Circumference; WHO, World Health Organization; WHOQOL-Bref, WHO Quality of Life-Brief scale.

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The World Health Organization (WHO, 2013) describes overweight and obesity as "*abnormal or excessive fat accumulation that may impair health*" defining individuals with a Body Mass Index (BMI) over 25 as overweight, and those with a BMI over 30 as having obesity. A key indicator of health risks related to overweight and obesity is Waist Circumference (WC) measurement: a WC over 88 cm for women and 102 cm for men increases the risk of heart disease and type 2 diabetes by 2–3 times (Flint et al., 2010; World Health Organization, 2011). Obesity has reached epidemic levels, with over one billion adults projected to have obesity by 2030. Addressing this issue is crucial for achieving Sustainable Development Goal target 3.4, which aims to reduce premature mortality from noncommunicable diseases by one-third by 2030 (Chong et al., 2023). Obesity is 1.5 to 4 times more prevalent (Coodin, 2001; Gurpegui et al., 2012; Silverstone et al., 1988) with higher WC (Shah et al., 2019) among people with SSD than in the general population. The challenge of managing weight in individuals with SSD stems from a complex blend of disease-related factors, most notably the use of Antipsychotic (AP) medications. These medications are associated with increased visceral and subcutaneous fat (Smith et al., 2021). Recent analyses utilising imaging techniques to assess adiposity have revealed that individuals with SSD exhibit greater fat accumulation than healthy controls (hereafter, "controls"), exacerbated by AP treatment. The risk of significant weight gain and higher WC linked to psychotropic medications intersects with a complex matrix of genetic, lifestyle, and environmental factors: the ramifications of obesity in people with SSD are profound, influencing cardiovascular health, diabetes risk, and overall mortality. Some studies indicate that people with SSD and obesity often experience diminished physical fitness, self-esteem, vitality, and global health compared to their counterparts with normal-weight (Kolotkin et al., 2008). The detrimental impacts on body image and life enjoyment can lead to further weight gain and medication nonadherence (Catapano and Castle, 2004).

Understanding the interplay between weight and WC changes and Physical Activity (PA) is essential for grasping the full scope of health challenges faced by people with SSD. Evidence suggests that disruptions in PA contribute significantly to weight issues in this group (Coventry et al., 2019; Strassnig et al., 2014): individuals with SSD typically engage in less PA compared to healthy peers (Martinelli et al., 2023; Wildgust et al., 2010). Sedentary habits and low PA levels are often linked with male sex (Vancampfort et al., 2017), unemployment, and higher smoking rates. Lower PA levels are also associated with more severe negative symptoms and poor dietary patterns (Gorczynski et al., 2018). Additionally, obesity-related decreases in cardiorespiratory fitness are predictive of cardiovascular disease and potentially mortality (Kodama et al., 2009).

Previous research into PA levels among people with SSD has often relied on self-reported data (questionnaires), which may introduce errors (Vancampfort et al., 2011). The few studies employing accelerometers (Duncan et al., 2017), which provide objective estimates of PA, sleep-wake rhythms, and caloric consumption, have demonstrated altered motor patterns and sedentary behaviour in people with SSD compared to controls (Janney et al., 2013; Kluge et al., 2018; Naslund et al., 2016; Tahmasian et al., 2013; Wee et al., 2019). Consistently, our previous research found SSD patients have lower levels of PA than controls (Oliva et al., 2023; Zarbo et al., 2023).

To date, no studies have investigated, using wearable devices, the relationship between PA and BMI, weight and WC in patients with SSD as well as compared SSD activity levels to controls. Furthermore, a significant gap exists in understanding whether individuals receiving outpatient care ("outpatients") exhibit distinct patterns of PA, BMI, weight or WC compared to those residing in institutional settings ("residents"). Therefore, this study aims to examine whether potential disparities exist in these parameters between different groups of participants (residents and outpatients with SSD, and healthy controls).

2. Methods

2.1. Study setting

This study was conducted in 10 sites involved in the whole DiAPAson project: these include seven Departments of Mental Health (DMHs), one clinical research centre (IRCCS) and two Residential Facilities (RFs).

2.2. Eligibility and recruitment

We included patients who met the DSM-5 criteria required for an SSD diagnosis (American Psychiatric Association, 2013) aged between 20 and 55 years, and able to speak and write in Italian (see Supplementary Fig. 1). We excluded patients who (i) were unable to provide informed consent or who had severe cognitive deficits, i.e., a Mini-Mental State Examination (MMSE) (Cockrell and Marshal, 2002; Measso et al., 1993) corrected score lower than 24; (ii) had a recent (in the last 6 months) diagnosis of substance use disorder according to DSM-5 criteria based on medical records; and (iii) had a history of clinically significant head injury or cerebrovascular/neurological disease.

The study was conducted following the Helsinki Declaration (World Medical Association, 2013) and, before the study began, all recruited participants approved and signed an informed consent. Local Ethical Committees approved the study (see specific section below).

Sample size calculation has been thoroughly described in the study protocol (de Girolamo et al., 2020a). From October 2020 to October 2021, 127 patients with a diagnosis of SSD and aged 20–55 years were recruited and assessed. *Outpatients* were community-dwelling patients with SSD who were approached consecutively at the outpatient units of the 7 DMHs for potential participation until the recruitment target was achieved. At the IRCCS and in the RFs the facility chiefs prepared an alphabetical list of patients with SSD present on an index day; based on this list, *residents* were consecutively invited to participate in the study until the recruitment target was achieved.

Controls were recruited by public advertisements and snowball sampling procedures and were matched by sex and age group (i.e., 20–24, 25–29, 30–34, 35–39, 40–44, 45–49 and 50–55) with the clinical sample.

Two hundred and thirty-seven participants met the inclusion criteria for accelerometer monitoring and reporting data required for BMI calculation: 126 patients with SSD (71 residents; 55 outpatients) and 111 controls were included in the final analyses (see Supplementary Fig. 1).

Participants were provided with detailed information about the study and had an opportunity to ask questions. The assessment with the biosensor was preceded by a training session where the research assistant provided instructions on the procedures and their effective execution. Following the monitoring, a briefing session was conducted by the same research assistant to gather information on study acceptability and feasibility. During this session, outpatients and controls received €25 for travel expense reimbursement.

2.3. Clinical assessments

Participants enrolled in the DiAPAson project underwent a thorough assessment process employing a combination of clinician-administered instruments, including a collection of anthropometric variables and medical characteristics (see Table 1), and self-reported questionnaires. For detailed information regarding the assessment, please refer to the study protocol (de Girolamo et al., 2020b) and Appendix A (Supplementary Fig. 1 and Table 1).

2.4. Body Mass Index categorisation

All participants' anthropometric data were collected or measured by a research assistant following the instructions contained in the NIH

Table 1
Sociodemographic and medical characteristics of patients with ssd and controls.

Variables	Residents N=71(30.0 %)	Outpatients N=55 (23.2 %)	Controls N=111 (46.8 %)	p-value*
Sex, n (%)				
Female	19 (26.8 %)	26 (47.3 %)	45 (40.5 %)	0.056
Male	52 (73.2 %)	29 (52.7 %)	66 (59.5 %)	
Age				
Mean (CI)	42.9 (40.4;45.3)	39.3 (36.5;42.2)	41.6 (39.7;43.4)	0.200
Median (Min; Max)	46.0 (21.0; 55.0)	39.0 (20.0; 55.0)	43.0 (21.0; 55.0)	
Marital status, n (%)				
Not married/ Not cohabiting	61 (86.0 %)	44 (80.0 %)	28 (25.2 %)	**<0.001**
Married	3 (4.2 %)	3 (5.5 %)	57 (51.4 %)	
Not married/ cohabiting	2 (2.8 %)	2 (3.6 %)	20 (18.0 %)	
Divorced	5 (7.0 %)	4 (7.3 %)	5 (4.5 %)	
Widow	0 (0.0 %)	2 (3.6 %)	1 (0.9 %)	
Education years				
Mean (CI)	11.6 (10.8;12.3)	12.4 (11.8;13.2)	16.5 (15.6;17.4)	**<0.001**
Median (Min; Max)	12.0 (2.0; 20.0)	13.0 (8.0; 18.0)	17.0 (6.0; 27.0)	
Working status, n (%)				
Working	12 (16.9 %)	27 (49.1 %)	102 (91.9 %)	**<0.001**
Studying	3 (4.2 %)	6 (10.9 %)	8 (7.2 %)	
Not working	56 (78.9 %)	22 (40.0 %)	1 (0.9 %)	
Charlson Comorbidity Index (CCI)				
Mean (CI)	1.1 (0.75;1.45)	0.4 (0.11;0.69)	0.5 (0.35;0.65)	**0.001**
Median (Min; Max)	1.0 (0.0; 8.0)	0.0 (0.0; 7.0)	0.0 (0.0; 4.0)	
Weight				
Mean (CI)	78.5 (74.3;82.2)	84.7 (78.8;90.6)	72.6 (69.9;75.4)	**<0.001**
Median (Min; Max)	77.0 (53.0; 125.0)	83.0 (42.0; 150.0)	71.0 (44.0; 115.0)	
Height				
Mean (CI)	173.8 (171.9;175.6)	170.3 (167.1;172.7)	172.8 (171.0;174.5)	**<0.001**
Median (Min; Max)	174.0(152.0; 195.0)	171.0(150.0; 190.0)	173(145.0; 198.0)	
Body Mass Index (BMI)				
Mean (CI)	25.9 (24.7;27.0)	29.1 (27.4;30.8)	24.2 (23.5;24.9)	**<0.001**
Median (Min; Max)	25.4 (18.5; 39.5)	27.4 (16.6; 44.8)	23.9 (17.7; 35.5)	
Waist circumference (WC)				
Mean (CI)	98.1 (94.8;101,4)	103.4 (98.6;108.2)	88.5 (86.2;90.8)	**<0.001**
Median (Min; Max)	95.0 (74.0; 144.0)	104.0 (71.0; 155.0)	89.0 (59.0; 123.0)	
Smoking (cigarettes/day)				
Mean (CI)	10.8 (8.4;13.2)	7.9 (4.9;10.9)	1.8 (1.0;2.6)	**<0.001**
Median (Min; Max)	10.0 (0.0; 40.0)	0.0 (0.0; 40.0)	0.0 (0.0; 22.0)	

*Pearson's Chi-squared test with simulated p-value (based on 2000 replicates); One-way ANOVA; Bold values indicate statistical significance at the $p < 0.05$ level.

guidelines (NIH, 2000). According to Cooper et al. (2000), all participants fell into three different BMI ranges: Normal Weight was defined as BMI<24.9, Overweight as 25 < BMI<29.9, and Obese as BMI≥30.

2.5. Assessment of PA and data processing

PA was monitored through the wearable accelerometer-based biosensor ActiGraph GT9X Link, which is a validated triaxial accelerometer that includes a gyroscope, magnetometer, accelerometer, and Bluetooth capability manufactured by ActiGraph (Pensacola, FL 3250, USA). The Actigraph was worn on the non-dominant wrist for 7 consecutive days. Individual GT3X files were processed using the GGIR package (Van Hees, 2022) to estimate vector magnitude (VM) (Doherty et al., 2017), using 60 s epoch and default settings (calibration, no data imputation), with no threshold on daily valid hours. VM captures the total movement as a combination of accelerations along the three axes. To be included in the analyses each patient had to have at least 4 valid monitoring days, and for each day at least 10 valid hours of wearing time.

2.6. Statistical analysis

Data were summarised using mean, standard deviation (SD), median and interquartile range (IQR) for quantitative variables, while qualitative variables were presented as counts and percentages. Sociodemographic and clinical variables were compared among residents, outpatients, and controls using the $\chi 2$ test for categorical variables and the analysis of variance for continuous variables (ANOVA).

WC and weight were evaluated using multivariable ordinary least squares linear regression models with sex and age included as covariates. Weight was modelled by adding height as a covariate and reporting marginal average estimates for a fixed height (e.g., the average height in the study sample, 172 cm). To improve model interpretation, PA was also included in linear regression models as tertiles, defined using the tertiles thresholds computed on controls alone. The categorical BMI (obesity or normal weight) was further explored by using logistic regression on a reduced participant subset. Specifically, only patients with obesity and normal weight were considered, resulting in a sample size of 163 participants. This approach was undertaken because the control sample predominantly consisted of individuals with normal weight. Therefore, better stratification was deemed necessary to more accurately observe the effects of PA (standardised VM). In all models BMI, WC and weight were modelled on the log scale, to account for skewed residuals distribution. All models' assumptions were checked using graphical tools. The relationship between PA (standardised VM) and BMI, WC and weight were represented using smoothing curves based on loess (span = 1.7).

The analyses were performed using the R software system version 4.3.2. Results are reported as effect estimates and corresponding 95 % confidence intervals (CI). All tests were two-sided and assumed a 5 % significance level.

3. Results

3.1. Socio-demographic and medical characteristics of residents, outpatients and controls

Table 1 shows sociodemographic and health characteristics among three groups: residents (N=71, 30.0 %), outpatients (N=55, 23.2 %), and controls (N=111, 46.8 %). Marital status displayed a significant difference ($p < 0.001$), with most residents and outpatients being not married or not cohabiting compared to controls (respectively, 86.0 %, 80.0 % vs. 25.2 %). Education years also varied significantly ($p < 0.001$), with controls having more years of education on average (16.5, $CI_{95\%}$ 15.6–17.4 years). In terms of working status, a significant difference was observed ($p < 0.001$), with 91.9 % of controls working compared to only 49.1 % of outpatients and 16.9 % of residents. The Charlson Comorbidity Index (CCI) showed significant differences ($p = 0.001$): residents had a higher index (1.1, $CI_{95\%}$ 0.75–1.45) compared to controls (0.5, $CI_{95\%}$ 0.35–0.65) and outpatients (0.4, $CI_{95\%}$ 0.11; 0.69). Weight, height, BMI, WC, and smoking habits also showed significant differences among the groups ($p < 0.001$). Outpatients had the highest average weight (84.7 kg, $CI_{95\%}$ 78.8–90.6 kg), BMI (29, $CI_{95\%}$ 27.4–30.8), and WC (103.4 cm, $CI_{95\%}$ 98.6–108.2 cm), while controls had the lowest values in these measures. Residents were the tallest (173.8, $CI_{95\%}$ 171.9–175.6), while outpatients were the shortest (170.3, CI95% 167.1–172.7).

Residents smoked a significantly ($p < 0.001$) higher mean number of cigarettes per day (10.8, $CI_{95\%}$ 8.4–13.2) compared to outpatients (7.9, $CI_{95\%}$ 4.9–10.9) and controls (1.8, $CI_{95\%}$ 1.0–2.6).

3.2. Clinical characteristics of residents and outpatients

Table 2 presents the clinical characteristics of residents and outpatients. Psychiatric symptom severity, measured by the Brief Psychiatric Rating Scale (BPRS), was significantly ($p < 0.001$) higher in residents (48.8, $CI_{95\%}$ 45.6–52.0) compared to outpatients (41.2, $CI_{95\%}$ 38.4–44.0). Negative symptoms, assessed by the Brief Negative Symptom Scale (BNSS), were also higher ($p = 0.008$) in residents (24.6, $CI_{95\%}$ 21.2–28.0) than outpatients (17.6, $CI_{95\%}$ 13.5–21.6). Functioning, evaluated by the Specific Levels of Functioning Scale (SLOF), was significantly ($p < 0.001$) lower in residents (174.2, $CI_{95\%}$ 169.3–179.0) compared to outpatients (191.0, $CI_{95\%}$ 186.9–195.2). The use of AP and non-AP drugs was higher ($p < 0.001$) among residents (respectively, 2.6, $CI_{95\%}$ 2.33–2.97 and 0.6, $CI_{95\%}$ 0.47–0.80) compared to outpatients (respectively, 1.8, $CI_{95\%}$ 1.56–2.10 and 0.5, $CI_{95\%}$ 0.33–0.64). See Supplementary Table 1 for further information and references about the standardised assessment tools.

3.3. Association between PA and BMI, PA and WC and PA and weight within the groups of participants

Table 3 investigates the relationship between PA and BMI, WC and weight across the three participants' groups. For residents, a rise in PA was linked with a decrease in BMI (beta = 0.985, p = 0.43 $CI_{95\%}$0.950–1.022), WC (beta = 0.985, p = 0.47, $CI_{95\%}$0.947–1.025) and weight (beta = 0.978, p = 0.45, $CI_{95\%}$0.923–1.036). For outpatients, a higher level of PA was associated with a decrease in each BMI (beta = 0.972, p = 0.27, $CI_{95\%}$0.923–1.023), WC (beta = 0.975, p = 0.24, $CI_{95\%}$0.933–1.018) and weight (beta = 0.975, p = 0.34, $CI_{95\%}$0.926–1.027). On the contrary, among controls, an increase of PA was associated with a marginal increase of BMI (beta = 1.034, p = 0.19, $CI_{95\%}$0.984–1.086), WC (beta = 1.015, p = 0.47, $CI_{95\%}$0.975–1.056) and weight (beta = 1.040, p = 0.09, $CI_{95\%}$0.993–1.090). Fig. 1 and Fig. 2 show the relationship between different levels of PA (expressed as standardised values of VM) and anthropometric measures (e.g., BMI and WC) across all participants.

Table 2
Clinical characteristics of patients (residents vs. outpatients).

Variables	Residents N=71 (56.3 %)	**Outpatients** N=55 (43.7 %)	p-value*
Lifetime duration (years) of psychiatric hospitalisation			
Mean (CI)	3.2 (2.24;4.18)	0.3 (0.3;0.3)	0.500
Median (Min; Max)	2.0 (0.0; 22.4)	0.3 (0.3; 0.3)	
(Missing)	0	54	
Mini Mental State Examination (MMSE)			
Mean (CI)	27.1 (26.7;27.5)	27.6 (27.32;28.0)	0.071
Median (Min; Max)	27.3 (24.0; 30.0)	27.9 (24.1; 29.0)	
Brief Psychiatric Rating Scale (BPRS)			
Mean (CI)	48.8 (45.6;52.0)	41.2 (38.4;44.0)	**<0.001**
Median (Min; Max)	47.0 (27.0; 78.0)	39.0 (26.0; 70.0)	
(Missing)	0	0	
Brief Negative Symptom Scale (BNSS)			
Mean (CI)	24.6 (21.2;28.0)	17.6 (13.5;21.6)	**0.008**
Median (Min; Max)	23.0 (0.0; 55.0)	14.0 (0.0; 58.0)	
(Missing)	0	0	
Specific Levels of Functioning Scale (SLOF)			
Mean (CI)	174.2 (169.3;179.0)	191.0 (186.9;195.2)	**<0.001**
Median (Min; Max)	173.0 (125.0; 212.0)	193.0 (155.0; 214.0)	
(Missing)	0	2	
World Health Organization Quality of Life (WHOQOL-BREF)			
Mean (CI)	84.7 (81.6;87.8)	84.4 (81.2;87.5)	0.900
Median (Min; Max)	85.0 (59.0; 112.0)	85.0 (62.0; 120.0)	
(Missing)	3	4	
APs drugs			
Mean (CI)	2.6 (2.33;2.97)	1.8 (1.56;2.10)	**<0.001**
Median (Min; Max)	2.0 (1.0; 6.0)	2.0 (0.0; 4.0)	
Non-APs drugs			
Mean (CI)	0.6 (0.47;0.80)	0.5 (0.33;0.64)	**<0.001**
Median (Min; Max)	1.0 (0.0; 3.0)	0.0 (0.0; 2.0)	

*Pearson's Chi-squared test with simulated p-value (based on 2000 replicates); One-way ANOVA; Bold values indicate statistical significance at the $p < 0.05$ level AP=antypsychotics.

Table 3
Association between physical activity (pa) and body mass index (bmi), pa and waist circumference (wc), and pa and weight within the groups of participants.

	Participants*	**Estimate**	**CI**	**p-value****
Outcome: BMI	Controls	1.034	0.984–1.086	0.19
	Residents	0.985	0.950–1.022	0.43
	Outpatients	0.972	0.923–1.023	0.27
Outcome: WC	Controls	1.015	0.975–1.056	0.47
	Residents	0.985	0.947 – 1.025	0.47
	Outpatients	0.975	0.933 – 1.018	0.24
Outcome: Weight	Controls	1.040	0.993–1.090	0.09
	Residents	0.978	0.923–1.036	0.45
	Outpatients	0.975	0.926–1.027	0.34

Linear regression models adjusted for age and sex The betas represent the proportional average variation (ratio between mean values) in the outcome for a unit increase in standardized vector magnitude (VM) (i.e. the variation for a 1 S. D. increase in VM), as a proxy of PA.
*Controls = 111 (46.8 %); Residents = 71 (30.0 %); Outpatients = 55 (23.2 %).
**Bold values indicate statistical significance at the $p < 0.05$ level.

3.4. Impact of PA on weight variations and VM across tertiles among controls, residents, and outpatients

To provide a more interpretable description of the association of PA with weight variations among patients, we estimated the height-adjusted average weight within subject groups and VM tertiles, using thresholds based on the control group's VM distribution levels (Table 4a). Consistent with previous results, outpatients in the lower VM tertile showed a substantial, though not statistically significant, reduction in average weight compared to outpatients in the higher tertile, with an average reduction of about 11 %, corresponding to approximately 9.7 kg (Table 4b). For controls and residents, weight remained constant across different VM tertiles but still exhibited substantially lower average values. Fig. 1 and Fig. 2 show the associations between different levels of PA (as standardised VM) and BMI and WC across all participants.

Fig. 3 illustrates that as PA levels increased from the first to the third tertile of controls, there was a corresponding decrease in weight and BMI among individuals with SSD (see also Fig. 4). Conversely, the transition from the first to the second tertile showed a less pronounced change among residents, while for outpatients and controls, the trend was in the opposite direction.

3.5. Sociodemographic comparison between groups of participants with normal weight and obesity after the exclusion of participants with overweight

Table 5 presents a descriptive comparison between groups of participants with normal weight and obesity, following the exclusion of participants who were overweight. Individuals with overweight were removed to create an 'extreme' control sample, allowing the observation of more pronounced changes according to PA. Among the 117 participants classified as normal weight, 70 (59.8 %) were controls, 33 (28.2 %) were residents, and 14 (12.0 %) were outpatients. In contrast, among the 46 participants classified as having obesity, 9 (19.6 %) were controls, 14 (30.4 %) were residents, and 23 (50.0 %) were outpatients.

Weight, BMI, and WC showed significant ($p < 0.001$) differences between the two groups. Participants with normal weight had a mean weight of 64.5 kg ($CI_{95\%}$ 62.84–66.1), whereas those with obesity had a mean weight of 101.0 kg ($CI_{95\%}$ 96.1–105.6). The mean BMI for

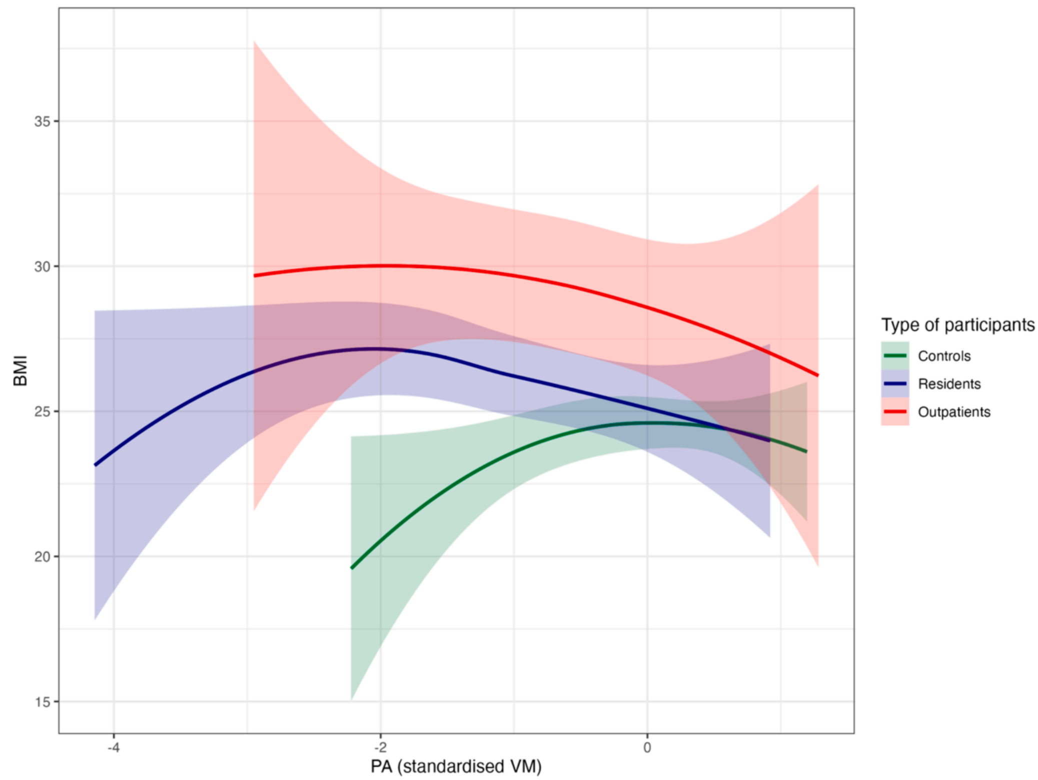

Fig. 1. Relationship between pa and bmi for all participants.

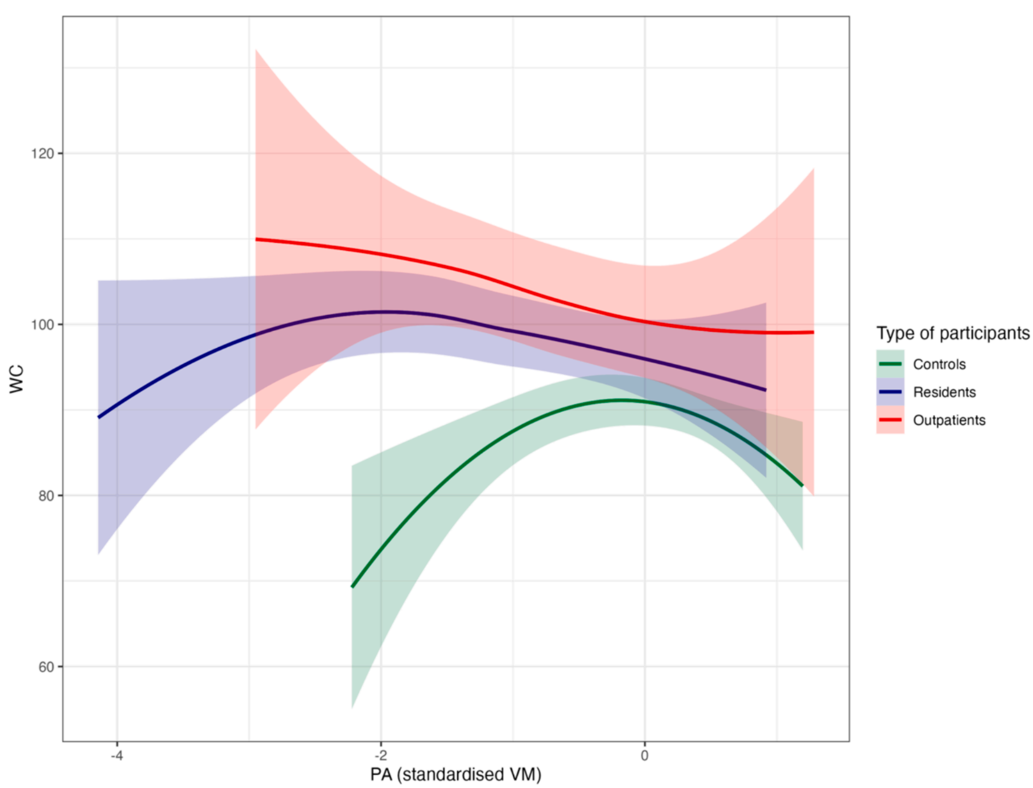

Fig. 2. Relationship between pa and wc for all participants.

participants with normal weight was 21.9 ($CI_{95\%}$ 21.5–22.2), while for participants with obesity, the mean BMI was 34.0 ($CI_{95\%}$ 32.9–35.2). Moreover, participants having normal weight registered a mean WC of 84.3 cm ($CI_{95\%}$ 82.8–85.8), whereas those with obesity had a mean WC of 116.0 cm ($CI_{95\%}$ 112.0–119.9).

Table 4
(a) Weight divided by tertiles of controls across participant type.

Participants, n (%)	VM	Response (Weight in Kg)	CI	p-value*
Controls N=111 (46.8 %)	1st tertile	69.3	65.4–73.4	**<0.001**
	2nd tertile	70.3	66.4–74.5	**<0.001**
	3rd tertile	71.1	67.1–75.3	**<0.001**
Residents N=71 (30.0 %)	1st tertile	74.7	71.1–78.5	**<0.001**
	2nd tertile	69.1	60.2–79.2	**<0.001**
	3rd tertile	75.4	67.8–83.9	**<0.001**
Outpatients N=55 (23.2 %)	1st tertile	85.2	80.4–90.3	**<0.001**
	2nd tertile	85.4	76.0–96.1	**<0.001**
	3rd tertile	75.9	66.8–86.1	**<0.001**

Linear regression adjusted for age and sex; fixed height (172 cm); 1st, 2nd, 3rd tertiles of controls' physical activity (standardized VM) *Bold values indicate statistical significance at the $p < 0.05$ level VM=vector magnitude

(b) Weight contrasts based on pa level (controls tertiles) and participant type

Participants, n (%)	Comparisons	Estimate	CI	p-value*
Controls N=111 (46.8%)	2nd / 1st	1.016	0.937–1.102	0.71
	3rd / 1st	1.027	0.947–1.114	0.52
Residents N=71 (30.0%)	2nd / 1st	0.925	0.801–1.068	0.29
	3rd / 1st	1.009	0.899–1.133	0.88
Outpatients N=55 (23.2%)	2nd / 1st	1.003	0.881–1.141	0.97
	3rd / 1st	0.890	0.775–1.023	0.10

Linear regression adjusted for age and sex; fixed height (172 cm); 1st, 2nd, 3rd tertiles of controls' PA (standardised VM) *Bold values indicate statistical significance at the $p < 0.05$ level.

3.6. Relationships between PA and BMI within groups with normal weight and obesity, after the exclusion of participants with overweight

Table 6 investigates the relationship between BMI categories (normal weight vs. obesity) across the three participant groups. Increased PA was associated with lower risks of obesity across all participant categories: controls (OR=0.984, $p = 0.75$, $CI_{95\%}$0.888–1.090), residents (OR=0.932, $p = 0.20$, $CI_{95\%}$0.837–1.038), and outpatients (OR=0.878, $p = 0.11$, $CI_{95\%}$0.750–1.029). Overall, no significant effects were observed among the participants.

4. Discussion

The present study aimed to explore the intricate relationship between PA and BMI, WC and weight among individuals with SSD. To the best of our knowledge, this is the first investigation into the interaction of these variables using actigraphy and comparing these metrics with a substantial control cohort.

Our findings confirm that individuals with SSD have higher BMI, weight, and WC than controls (Coodin, 2001; de Girolamo et al., 2020b; Gurpegui et al., 2012; McWhinney et al., 2022; Shah and Kornstein, 2020; Silverstone et al., 1988), likely due to socio-demographic and clinical factors. Individuals with SSD were more often unmarried, less educated, and unemployed compared to controls, highlighting their broader socio-economic challenges which can affect health outcomes. Health-related characteristics further underscore disparities: residents had a higher CCI, indicating a greater burden of comorbid conditions, consistent with evidence showing higher physical comorbidity in individuals with SSD (Smith et al., 2013). In a large Italian survey of 2,962 patients living in RFs, medical comorbidities were found only in a minority of residents, with motor disabilities at 8 % and cardiovascular problems at 7.5 % (de Girolamo et al., 2005).

Smoking habits varied significantly, with residents smoking the most. Smoking is a risk factor for both psychiatric conditions and obesity, complicating their health profile. Despite residents having more

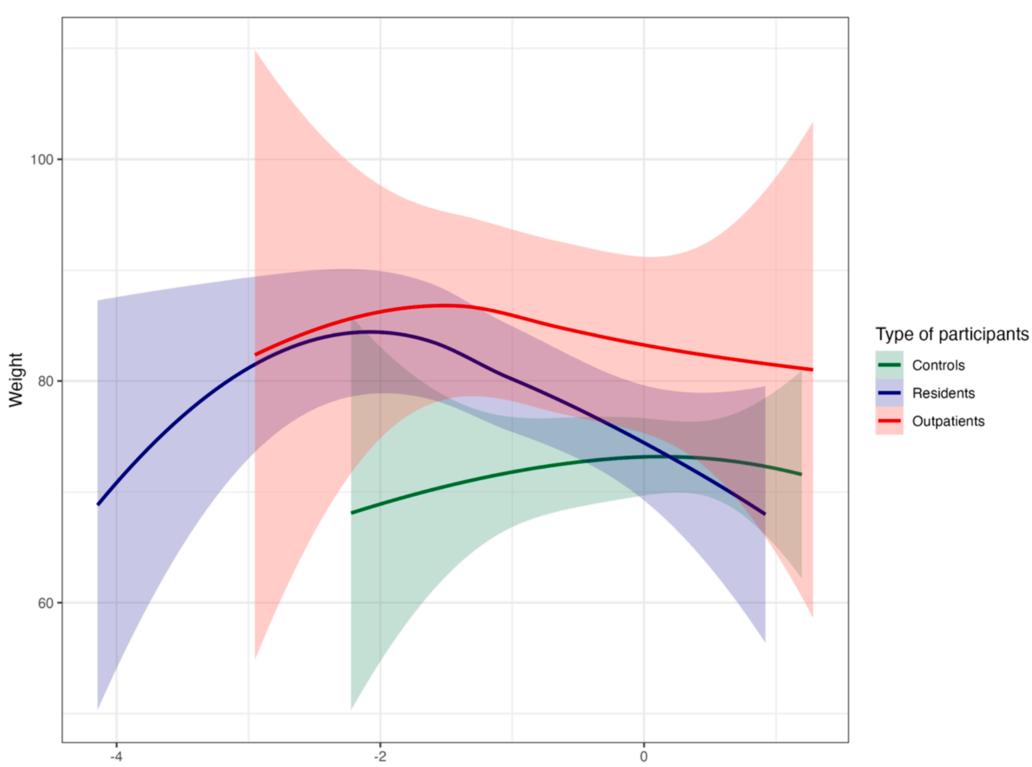

Fig. 3. Relationship between pa and weight for all participants.

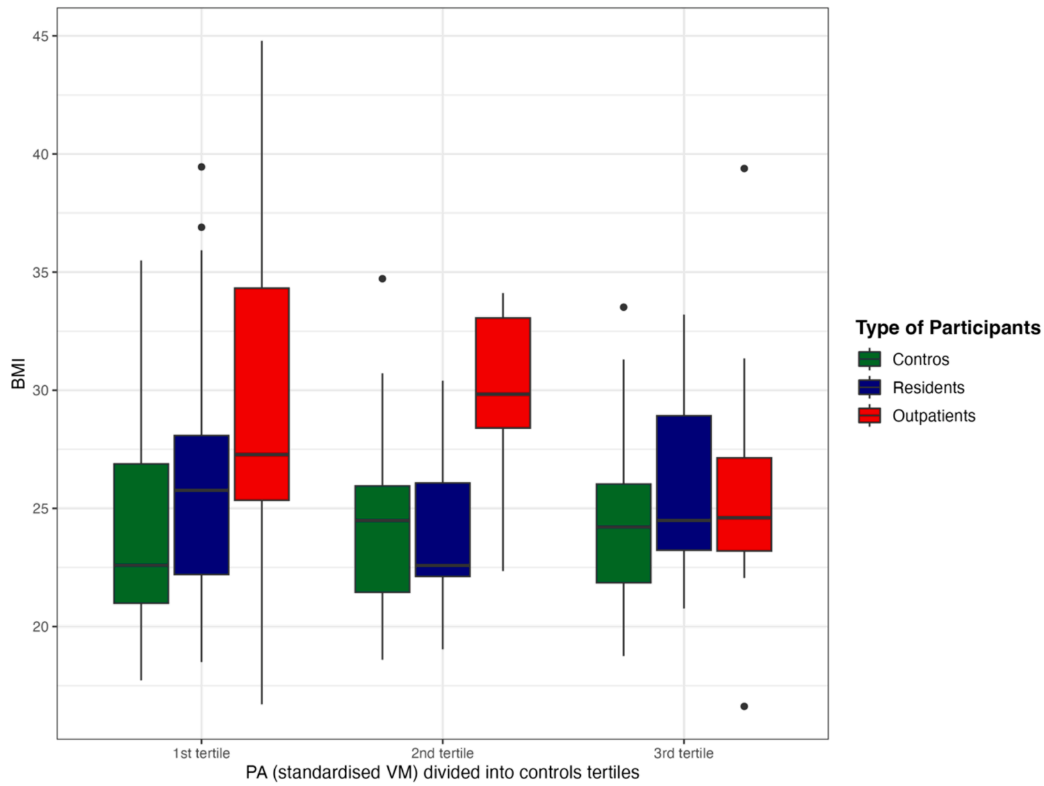

Fig. 4. BMI distribution by pa tertiles of controls participants.

Table 5
Comparison between participants with normal weight and obesity excluding participants with overweight.

Variables	**Normal Weight** N=117 (71.8 %)	**Obesity** N=46 (28.2 %)	p-value*
Participants, n (%)			
Controls	70 (59.8 %)	9 (19.6 %)	**<0.001**
Residents	33 (28.2 %)	14 (30.4 %)	
Outpatients	14 (12.0 %)	23 (50.0 %)	
Sex, n (%)			
Female	51 (43.6 %)	19 (41.3 %)	0.900
Male	66 (56.4 %)	27 (58.7 %)	
Age			
Mean (SD)	40.0 (38.0;41.9)	41.6 (38.7;44.5)	0.400
Median (Min; Max)	41.0 (21.0; 55.0)	43.0 (22.0; 55.0)	
Weight			
Mean (CI)	64.5 (62.84;66.1)	101.0 (96.1;105.6)	**<0.001**
Median (Min; Max)	64.0 (42.0; 86.0)	98.0 (73.0; 150.0)	
Body Mass Index (BMI)			
Mean (CI)	21.9 (21.5;22.2)	34.0 (32.9;35.2)	**<0.001**
Median (Min; Max)	22.1 (16.6; 25.0)	33.2 (30.1; 44.8)	
Waist circumference (WC)			
Mean (CI)	84.3 (82.8;85.8)	116.0 (112.0;119.9)	**<0.001**
Median (Min; Max)	84.0 (65.0; 114.0)	116.3 (93.5; 155.0)	
(Missing)	0	2	

* Pearson's Chi-squared test with simulated p-value (based on 2000 replicates); One-way ANOVA; Bold values indicate statistical significance at the $p < 0.05$ level.

Table 6
Impact of pa on bmi categories (normal weight vs. obesity) following exclusion of participants with overweight.

Participants, n (%)	Odds Ratio*	CI	p-value**
Controls (N=79, 48.5 %)	0.984	0.888–1.090	0.75
Residents (N=47, 28.8 %)	0.932	0.837–1.038	0.20
Outpatients (N=37, 22.7 %)	0.878	0.750–1.029	0.11

*Logistic regression analysis adjusted for sex, age and height. An Odds Ratio (OR) greater than 1 suggests that higher PA is linked with higher odds of obesity, while an OR less than 1 indicates lower odds of obesity with increased PA.
** Bold values indicate statistical significance at the $p < 0.05$ level.

severe psychopathology, lower functioning and higher medication prescriptions (AP and non-AP) than outpatients, outpatients exhibited the highest average weight, BMI, and WC. This highlights the importance of assessing visceral adiposity rather than solely relying on BMI to evaluate metabolic health risks in individuals with SSD. This finding aligns with previous research on central fat distribution (Lean et al., 1995) and potential associations between weight and WC (Yuan et al., 2022).

The difference in BMI and WC between residents and outpatients may be due to outpatients lacking a regulated diet and a monitored lifestyle which can be found in RFs, where meals are catered by external providers under the supervision of a nutritionist. These factors suggest that the controlled environment of RFs (Martinelli et al., 2022) contributes to the observed differences.

The investigation into BMI, WC and weight variation with PA has revealed intriguing findings. Increased PA was associated with reductions in BMI, WC and weight among residents and outpatients, aligning with the established benefits of PA on body composition (Cárdenas Fuentes et al., 2018; Dagan et al., 2013). This underscores the potential for PA to lower BMI, WC and weight. Furthermore, this effect appears more pronounced among outpatients, possibly influenced by socio-demographic, clinical factors and living accommodations that widen health disparities. An unexpected trend emerged among controls: a positive association between PA and BMI, WC and weight. This phenomenon may stem from most controls starting with a normal weight or only slightly overweight. Detecting significant changes in BMI due to variations in PA levels can be challenging in individuals within the normal weight range.

By categorising participants based on VM tertiles, the study aimed to assess the impact of PA on weight changes. Outpatients, who showed the highest BMI, WC, and weight, demonstrated a potential weight variation of about 10 kg with PA levels like the first tertile of controls. Controls exhibited less weight fluctuation, likely due to their normal weight status. Excluding overweight participants allowed for clearer observations of PA effects on BMI, revealing a negative association across all groups, except for participants with normal weight who showed BMI increase with PA, suggesting possible muscle gains or increased calorie consumption in response to PA (Dhar and Purwar, 2023). Based on our findings, outpatients with initially higher BMI, WC, and weight may achieve a significant weight reduction of around 10 kg by engaging in PA levels similar to those in the first tertile of controls. This underscores the potential benefits of structured exercise interventions tailored to outpatients, highlighting their capacity to improve metabolic health and reduce BMI in our study sample.

These results suggest that differences in weight, BMI, and WC between groups with normal weight and obesity highlight the significant health challenges faced by individuals with SSD, with increased PA being potentially beneficial.

4.1. Strengths and limitations

The brief 1-week study duration restricts our ability to extrapolate findings to long-term levels of PA, underscoring the necessity for extended follow-up periods in future investigations. Performing direct, accurate medical assessments of patients with SSD has not been feasible, and this may have prevented the recognition of some medical comorbidities. Additionally, the COVID-19 pandemic presented challenges regarding outdoor activities, which may have impacted our data collection and subsequent analysis (Lasalvia et al., 2023; Martinelli and Ruggeri, 2020).

One limitation of our study pertains to the composition of the control sample, which lacks wider BMI stratifications. The observed negative association between PA and BMI/weight/WC likely reflects the challenge of achieving significant weight reduction through PA among individuals starting with a normal weight or slightly overweight. Detecting substantial changes in BMI due to PA variations is difficult in individuals within the normal weight range. However, our control sample closely mirrors the BMI distribution of the general Italian population, with approximately 63 % classified as Normal Weight, comparable to 57.0 % in the PASSI surveillance system (Nobile et al., 2022). Participants with overweight and obesity accounted for 29.1 % and 9.8 %, respectively, compared to 32.6 % and 10.4 % in PASSI.

Moreover, the limited representation of individuals with obesity in both control and patient groups may have affected observed relationships and hindered the detection of nuanced effects of PA on BMI, and WC across different weight categories. Future research should employ targeted sampling methods to include a broader range of BMI categories, particularly individuals with obesity, to enhance understanding of how PA influences these health outcomes.

5. Conclusions

This study provides insights into the sociodemographic, medical, and clinical characteristics of individuals with SSD, identifying factors contributing to their health vulnerabilities. Comparing patients with SSD with healthy controls and distinguishing between residents and outpatients clarified various factors influencing health outcomes. Patients were more likely to be unmarried, unemployed, and less educated. Residents had more medical comorbidities, while outpatients had higher BMI, weight, and WC. Residents also reported more severe psychopathology, lower functioning, and greater use of psychopharmacological medications. Higher PA levels did not significantly decrease BMI, WC, or weight, though outpatients showed an estimated weight reduction of about 9.7 kg from the lowest to the highest PA tertile for an average-height subject. Significant differences in weight, BMI, and WC were observed between the groups with normal weight and obesity. Additionally, WC emerged as a crucial indicator of weight changes following increased PA, and this emphasises its role in assessing metabolic changes.

In conclusion, our findings offer valuable insights for targeted interventions aimed at improving PA and managing body fat among individuals with SSD. Understanding lifestyle disparities between patients in different settings and identifying influencing factors can inform tailored interventions to enhance PA and health outcomes. Furthermore, the study underscores the need to address sociodemographic disadvantages and medical comorbidities to mitigate health vulnerabilities in this population.

6. Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals.

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CRediT authorship contribution statement

Alessandra Martinelli: Conceptualization, Validation, Visualization, Writing – original draft, Writing – review & editing. **Silvia Leone:** Conceptualization, Validation, Visualization, Writing – original draft, Writing – review & editing. **Manuel Zamparini:** Data curation, Formal analysis, Methodology, Software. **Martina Carnevale:** Data curation, Formal analysis. **Ian D. Caterson:** Supervision, Validation, Writing – review & editing. **Nicholas R. Fuller:** Supervision, Validation, Writing – review & editing. **Stefano Calza:** Data curation, Formal analysis, Methodology, Software, Validation. **Giovanni de Girolamo:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, 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.

Data availability

Dataset referring to this manuscript is published with restricted access on Zenodo platform and accessible at this link: https://zenodo.org/records/10259894.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bbi.2024.09.007.

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