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Bayesian network analysis uncovers physical activity–mood dynamics: Insights from the DiAPAson study

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Original Article

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Abstract

Background. Individuals with schizophrenia spectrum disorders (SSDs) frequently exhibit low levels of physical activity (PA) and mood disturbances, both of which contribute to functional impairment and poorer long-term outcomes. Despite growing evidence linking PA and affective regulation, little is known about the real-time, bidirectional relationship between these domains in SSD.

Methods. In this multicenter observational study (DiAPAson project), 120 patients with SSD and 113 age- and sex-matched healthy controls (HC) underwent a 7-day ecological assessment combining smartphone-based Ecological Momentary Assessment (EMA; 8 prompts/day) and continuous wrist-worn actigraphy. We analyzed the dynamic associations between PA and mood using generalized linear mixed models (GLMMs) and Bayesian models with lagged temporal structures.

Results. GLMMs revealed significantly lower daily mood in SSD compared to HC (estimate = −0.33, 95% CI: −0.53 to −0.12; $p = .002$), but no significant day-level association between PA and mood. In contrast, Bayesian models uncovered robust within-day, bidirectional associations in HC such that higher PA levels were followed by higher subsequent mood and, conversely, better mood predicted higher subsequent PA (PA → mood: posterior probability = 99.9%; mood → PA: 89.6%). In SSD, these within-day couplings were attenuated and more heterogeneous across individuals (PA → mood: 87.2%; mood → PA: 67.5%).

Conclusions. PA and mood are dynamically and bidirectionally linked within short temporal windows throughout the day, with stronger coupling in HC than in SSD. The substantial individual variability observed in SSD highlights the need for personalized, sensor-informed interventions, as aggregated analyses may obscure clinically relevant microtemporal dynamics.

Introduction

Schizophrenia spectrum disorders (SSDs) are severe and chronic psychiatric conditions affecting approximately 1% of the global population (McGrath et al., 2004). These disorders profoundly impact multiple domains of quality of life, including physical health, social functioning, and psychological well-being (Dong et al., 2019). Among lifestyle factors, physical inactivity is particularly concerning, as individuals with schizophrenia have significantly lower levels of physical activity (PA) compared to the general population (Allison et al., 1999; Andersen et al., 2018; Ganguli, 1999; Scheewe et al., 2019; Stubbs, Williams, Gaughran, & Craig, 2016; Vancampfort et al., 2017; Zarbo et al., 2023), often failing to meet the World Health Organization's (WHO) recommended PA guidelines (Bull et al., 2020). The consequences of this sedentary lifestyle extend beyond physical health, as numerous studies have demonstrated a strong association between low PA levels and poor mental health outcomes (Ohi et al., 2019). For example, meta-analytic data indicate that physical inactivity is associated with a 25–30% increased risk of developing depression in the general population (Schuch et al., 2018).

In individuals with SSD, the relationship between PA and mood disturbances appears to be even more pronounced compared to HC. Research has shown that lower PA levels are associated with greater severity of negative symptoms (e.g., anhedonia, blunted affect) and higher levels of depressive symptoms (D'Anna et al., 2023; Dauwan et al., 2021; Pearce et al., 2022; Pieters et al., 2021; Zarbo et al., 2023). Additionally, physical inactivity exacerbates cognitive deficits, reduces social engagement, and is linked to higher antipsychotic medication dosages, poorer treatment adherence, and lower overall functioning (Damme et al., 2022; Stubbs et al., 2016).

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Recent technological advancements, such as Ecological Momentary Assessment (EMA) and wearable accelerometer-based biosensors, offer innovative methodologies to investigate the daily life experiences of individuals with SSD thoroughly. EMA provides real-time, ecologically valid assessments of individuals' emotional and behavioral experiences (Shiffman, Stone, & Hufford, 2008), while wearable accelerometer-based biosensors enable continuous and objective PA monitoring (Arabboev, Begmatov, and Nosirov, 2024). However, despite their potential, the application of these methodologies in SSD research remains limited.

Existing studies on SSD have rarely combined high-frequency EMA with continuous accelerometry to quantify real-time, bidirectional associations between PA and mood in daily life. Building on this gap, the present study uses a multimodal ecological approach to characterize PA–mood dynamics and diurnal patterns in individuals with SSD compared with healthy controls (HC). Specifically, as shown in Figure S1 in Supplementary Material 1, we utilized: (1) EMA delivered via smartphone 8 times daily to assess real-time mood states (depicted by emoji scales, with smartphone notifications shown along the temporal timeline below); (2) ActiGraph wearable accelerometers to objectively monitor PA (represented by running figures), analyzing movement intensity and duration using ENMO metrics, with directional arrows indicating the temporal dependencies. By systematically integrating these methodologies, this study aims to:

- Examine the strength and direction of associations between PA levels and mood, while controlling sociodemographic factors such as age and gender.
- Identify potential differences in PA and mood patterns between participants with SSD and HC.

Given the inherent complexity and bidirectionality of mood–PA interactions over time, we implemented complementary analytical strategies, combining Generalized Linear Mixed Models (GLMMs) for assessing day-level associations and Bayesian hierarchical models for modeling fine-grained, time-lagged dynamics. This combined approach addresses a critical limitation of previous research, which has typically relied on aggregated or static measures (Merikangas et al., 2019; Scheewe et al., 2019), potentially masking intraday temporal variability or the potential bidirectionality of these processes. By leveraging this dual strategy, our study aims to capture the temporal structure and individual variability of mood and PA interplay in everyday life, offering novel insights for personalized, sensor-informed interventions in SSD.

Methods

Study setting

This cohort study was conducted at a subset of sites participating in the Italian national DiAPAson project. These included seven Departments of Mental Health, which enrolled both outpatients and residentials, one clinical research center, and two residential facilities, which exclusively recruited residents.

Eligibility criteria and recruitment

Between October 2020 and October 2021, a total of 137 eligible participants with SSD (79 residents, 58 outpatients) and 113 HC (matched for age and sex) were initially recruited from the 10 participating centers for ecological monitoring. Participants were individuals aged 20–55 years with a diagnosis of SSD according to DSM-5 criteria (American Psychiatric Association, 2013). Eligibility required fluency in spoken and written Italian. Exclusion criteria included inability to provide informed consent, significant cognitive impairment (Mini-Mental State Examination score <24, adjusted for age and education), recent diagnosis (within the past 6 months) of substance use disorder per DSM-5 criteria, history of clinically relevant head trauma, or presence of cerebrovascular or other neurologic conditions. Figure 1 presents a flowchart illustrating the patient recruitment and allocation process, including the total number of patients assessed for eligibility, reasons for exclusion, and final allocation into study groups. Of the 246 enrolled participants, 13 were excluded from the final analysis due to incomplete data acquisition: 8 participants with SSD provided no EMA responses, and 5 participants (of which 2 were HC and 3 were people with SSD) had no actigraphy recordings. Given that this investigation specifically examines the relationship between subjective mood states and patterns in PA, participants with missing data for either measure were excluded to ensure the accuracy of data analysis. To guarantee a balanced comparison, HC were recruited through public advertisements and snowball sampling techniques and were matched with the clinical sample based on sex and age group (20–24, 25–29, 30–34, 35–39, 40–44, 45–49, and 50–55 years). Sample size calculations are detailed in the study protocol (de Girolamo et al., 2020). Participants received comprehensive information about the study and had the opportunity to ask questions. The treating clinician completed the assessment tools partially, while Research Assistants (RAs) supported self-reported questionnaires when necessary. To minimize methodological



Figure 1. Study enrollment flowchart.

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biases, standardized clinical measures were employed (see the following sections). Before the ecological monitoring, participants attended a briefing session, during which RAs provided instructions on study procedures and best practices. The monitoring period concluded with a debriefing session, where RAs collected feedback on study acceptability and feasibility (Zarbo et al., 2022). Outpatients and HC received € 25 as reimbursement for travel expenses. All participants provided written informed consent before participation.

Assessment instruments

Table 1 summarizes the sociodemographic, health, mood, and PA characteristics of the participants. The psychiatric history of participants with SSD was assessed using a structured ad hoc survey, capturing information on current diagnosis, illness duration, and lifetime psychiatric hospitalizations. Psychopathology was assessed using the 24-item Brief Psychiatric Rating Scale (BPRS) (Overall & Gorham, 1962; Zanello, Berthoud, Ventura, & Merlo, 2013). The severity of negative symptoms was measured with the Brief Negative Symptom Scale (BNSS) (Mucci et al., 2015; Strauss et al., 2012). Functional levels were evaluated using the 43-item Specific Levels of Functioning Scale (SLOF) (Mucci et al., 2014; Schneider & Struening, 1983). The World Health Organization Disability Assessment Schedule 2.0 (WHODAS 2.0) was used to assess disability levels (Ustün et al., 2010). Details on clinical assessment tools are provided in Table S1 in Supplementary Material 2.

Assessment of daily time use and emotions

Self-reported emotions and daily activities were assessed using a smartphone-based EMA application developed specifically for the project. The mobile application consisted of three sections: current activities, interpersonal contacts, and mood. Items regarding mood were selected from the EMA Item Repository (https://osf.io/kg376/), which provides detailed psychometric information on validated EMA items. Participants received semirandomized notifications 8 times per day for 7 consecutive days, divided into the following time slots: 8–10 a.m., 10 a.m.–12 p.m., 12 p.m.–2 p.m., 2–4 p.m., 4–6 p.m., 6–8 p.m., 8–10 p.m., 10 p.m.–12 a.m. The mood was rated using different adjectives by asking participants how they felt that emotion at that current moment. The participants had to tap on the screen and select from a bar ranging from 0 to 100 (0 = not at all; 100 = a lot) for their emotions. According to the aims of the present study, the only responses that were considered for the assessment of mood were "Happy" and "Sad." Mood was computed as a "Happy" minus "Sad" score at each EMA evaluation, resulting in a score ranging from −100 (full sadness) to 100 (full happiness). Details of mood assessment can be found in Table S1 in Supplementary Material 3.

Assessment of physical activity and data processing

PA monitoring was conducted using the ActiGraph GT9X Link, a wearable accelerometer-based biosensor. Participants wore the ActiGraph on the nondominant wrist for 7 consecutive days, corresponding to the same period as the EMA monitoring. Individual GT9X files were processed to estimate Euclidean Norm Minus One (ENMO) (van Hees et al., 2013) using a 60s epoch with no threshold on daily valid hours. ENMO captures the total movement as a combination of accelerations along the three axes while adjusting for gravity via a fixed gravitational unit offset.

Table 1. Sociodemographic, health, mood, and PA characteristics

	HC (*N* = 113)	SSD participants (*N* = 120)	*p*-value
Sex, *n* (%)			.500
Female	46 (41.0%)	43 (36.0%)	
Male	67 (59.0%)	77 (64.0%)	
Age			.800
Mean (SD)	41.5 (10.2)	41.1 (10.6)	
Median (min; max)	43.0 (21.0; 56.0)	43.0 (18.0; 56.0)	
Marital status, *n* (%)			**<.001**[a]
Not married/not cohabiting	29 (26.0%)	98 (82.0%)	
Married	57 (50.0%)	6 (5.0%)	
Not married/cohabiting	20 (18.0%)	4 (3.3%)	
Divorced	6 (5.3%)	10 (8.3%)	
Widow	1 (0.9%)	2 (1.7%)	
Education (years)			**<.001**
Mean (SD)	16.6 (4.9)	12.0 (3.1)	
Median (min; max)	17.0 (6.0; 27.0)	12.0 (2.0; 21.0)	
Working status, *n* (%)			.006
Working	105 (92.9%)	75 (62.5%)	
Studying	7 (6.2%)	9 (7.5%)	
Not working	1 (0.9%)	36 (30.0%)	
Body mass index (BMI)			**<.001**
Mean (SD)	24.3 (3.8)	27.5 (5.7)	
Median (min-max)	23.9 (17.7–35.5)	26.8 (16.6–44.8)	
Smoking (cigarettes/day)			**<.001**
Mean (SD)	9.9 (5.6)	17.8 (9.3)	
Median (min-max)	10.0 (1.0–22.0)	20.0 (1.0–50.0)	
(Missing)			
Mood			**.004**
Mean (SD)	45.9 (21.2)	34.3 (36.6)	
Median (min; max)	44.8 (−5.2; 95.0)	35.8 (−100.0; 100.0)	
Physical activity (ENMO)			**<.001**
Mean (SD)	49.3 (12.3)	37.7 (13.3)	
Median (min; max)	47.6 (28.0; 97.0)	35.9 (13.9; 81.1)	

[a]Bold values indicate statistical significance at the $p < .05$ level.

Statistical analyses

Data were summarized using mean and standard deviation (SD) or median and interquartile range (IQR) for quantitative variables, counts, and percentages for qualitative variables. Comparisons of sociodemographic and clinical variables between participants with SSD and HC were performed using the Chi-squared test for categorical variables and the independent samples *t*-test for continuous variables.

The compliance to EMA evaluation among groups was evaluated by modeling the number of responses using a GLM with

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Negative Binomial distribution family, with the number of app requests received as an offset.

Modeling the relationship between mood and physical activity

To examine the association between daily mood and PA, we employed a GLMM with a skewed normal distribution, adjusting for group membership. The outcome variable was mood, and the main predictor was the standardized median daily value of PA preceding each EMA evaluation. The aim was to assess whether the strength of the day-level association between mood and PA differed across the SSD and HC groups.

Since the available full data structure is very rich, with repeated real-time evaluations of mood using EMA throughout the day, and continuous PA monitoring via ActiGraph, we developed a model to jointly estimate:

1. the association of PA with subsequent mood evaluations;
2. the association of mood levels with subsequent PA patterns.

For each EMA evaluation, we computed the average PA level during the 30 minutes preceding and following the mood assessment. The 30-minute temporal lag was selected based on theoretical, empirical, and practical considerations from the EMA literature. Acute postexercise affective responses, including mood enhancement, typically manifest within 15–30 minutes following activity cessation (Sala et al., 2024). This timeframe captures proximal bidirectional dynamics while balancing feasibility in real-time monitoring protocols (Dunton, Liao, Kawabata, & Intille, 2012; Shiffman et al., 2008). Shorter intervals (e.g., <10 minutes) are prone to noise from instantaneous fluctuations, whereas longer windows (>60 minutes) risk dilution by intervening variables like additional activity bouts or external triggers (Kanning, Ebner-Priemer, & Schlicht, 2013). This lag thus optimizes temporal specificity and signal-to-noise ratio for within-subject mood–PA associations in naturalistic settings, consistent with ambulatory assessment best practices. The model structure is graphically represented in Figure 2 using a Directed Acyclic Graph (DAG). For each participant group, we assumed:

- a direct association of PA (at time *t*-1) with mood (at time t, 30 minutes later);
- a reciprocal effect of mood on PA (evaluated 30 minutes later);
- first-order autocorrelation between successive mood evaluations;
- first-order autocorrelation between successive PA measurements;
- a potential confounding effect of the time slot in which mood was assessed, accounting for circadian influences on both mood and PA levels.

The DAG was translated into a statistical multilevel model fitted using a Bayesian Network approach (Bayesian Vector Autoregression, BVAR) with estimation based on Monte Carlo Markov Chain (MCMC) sampling, enabling multivariate and hierarchical analysis as required for our data structure.

The mood model accounted for:

- the PA → mood effect and its interaction with the participant group;
- a first-order lag effect;
- a time-slot effect;
- age and gender as covariates.

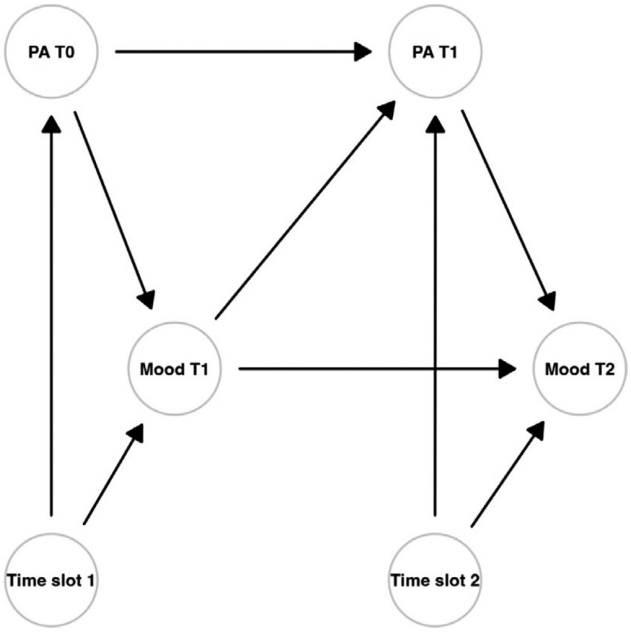


Figure 2. Directed acyclic graph (DAG) of physical activity and mood relationships. This figure shows the joint effect of physical activity on each mood evaluation and of mood levels on following PA patterns. For each EMA evaluation, the average PA level in the previous 30 minutes was estimated.

Similarly, the PA model accounted for:

- the mood → PA effect and its interaction with the participant group;
- a first-order lag effect;
- a time-slot effect;
- age and gender as covariates.

Before model fitting, PA and mood scores were standardized to facilitate the efficient exploration of the parameter space during MCMC sampling and to simplify prior distribution selection. Priors were chosen through prior predictive simulation via pre-data prediction inspection and by selecting prior parameters while producing plausible outcomes distributions. For both PA and Mood models, we used a likelihood based on a skewed normal distribution.

EMA analyses started from the 10:00–12:00 time slot, as the modeling procedure required a previous time point (t–1) for computing lagged effects. Thus, mood evaluations from the first time slot (08:00–10:00) were used as baseline predictors and were excluded from the outcome analyses.

Both GLMM and BVAR models also accounted for the number of EMA responses provided by each patient, therefore adjusting for the differential EMA response rate.

Model fitting was performed in R (version 4.5.2) using Stan (version 2.38.0) and Cmdstanr (Gabry, Češnovar, Johnson, & Bronder, 2024), using four independent chains with 1000 iterations each. Model fit adequacy was checked by evaluating R-hat values (to be approximately equal to 1), effective sample size, and visual inspection of chains' trajectories.

Results

Participant characteristics

Our final analysis included 120 participants with SSD (52.0%) and 113 HC (48.0%). As shown in Table 1, participants with SSD and

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HC were comparable in terms of age and sex. However, participants with SSD showed significantly lower educational and employment levels, were more often unmarried or not cohabiting, and had worse health indicators, including higher BMI, greater cigarette consumption, lower mood scores, and reduced PA levels.

Participants with SSD showed significant clinical impairment, moderate symptom severity (BPRS), prominent negative symptoms (BNSS), and marked functional limitations (SLOF and WHO-DAS 2.0) as shown in Table 2. On average, they had a long illness duration (17.7 years) and substantial psychiatric hospitalization history, with most of them hospitalized for over one year.

We evaluated the EMA response rate among patients, as a fraction of returned response over the number of alerts received. Both participant groups showed some degree of reduced compliance, but significantly less in SSD versus HC (Response rate = 0.73, CI 95% 0.66–0.81, $p < .001$) as shown in Table S2 in Supplementary Material 3.

Daily association between PA and mood

We examined the association between PA and mood using a GLMM with daily mean mood as the outcome variable and standardized median daily PA as the primary predictor. The model incorporated a skewed normal family distribution to account for the non-normal distribution of mood ratings. The analysis revealed no significant main effect of PA on mood ($\beta = 0.02$, 95% CI: −0.06 to 0.09, $P = .68$). However, participants with SSD had significantly lower daily mood levels compared with HC ($\beta = -0.29$, 95% CI: −0.55 to −0.07, $P = .01$). The interaction between PA and group (SSD versus HC) was not significant ($\beta = 0.08$, 95% CI: −0.02 to 0.18, $P = .133$). Diurnal pattern analysis (Figure 3) shows distinct mood trajectories between groups: HC exhibited progressive mood improvement throughout the day, reaching peak levels during evening hours (6:00 PM to 12:00 AM), whereas individuals with SSD displayed consistently lower and more stable mood patterns with minimal diurnal variation. EMA response level compliance did not show any relevant effect on mood levels (β =0.03, 95% CI: −0.05 to 0.11, $P = .504$). To further characterize interindividual variability in circadian patterns, Figures a and b in Supplementary Material 4 display the individual-level predicted trajectories of mood and PA across seven time slots (10:00–24:00) for HC and patients with SSD, respectively. Each dot represents a single individual's predicted value at a given time slot, with colors distinguishing the seven measurement windows. In HC, mood predicted values are densely clustered between approximately −1 and + 1 across all time slots, indicating a relatively homogeneous and stable circadian pattern with limited between-person dispersion. In patients with SSD, the distribution is markedly wider: while the majority of values overlap with the HC range, a substantial subgroup shows predicted mood values extending below −2 and reaching −4, with extreme low values observed across multiple time slots and particularly in the late afternoon and evening windows (14:00–22:00). A similar pattern is visible for PA: HC showing a progressive decline in predicted PA from the morning peak toward the late evening, with relatively compact individual spread; patients with SSD display the same directional trend but with considerably greater dispersion at each time slot, including extreme low outliers reaching −3 and below, predominantly in the 20:00–24:00 window. Taken together, these figures visually confirm that interindividual variability in both mood and PA circadian patterns is substantially greater in SSD than in HC, consistent with the pattern reported in the main text.

Table 2. Clinical characteristics of SSD participants

Variables	SSD participants ($N = 120$)
Illness duration	
Mean (SD)	17.7 (9.7)
Median (minimum; maximum)	18.0 (1.0–40.0)
Lifetime duration of psychiatric hospitalization (years), *n* (%)	
<1 years	54 (45.0%)
1–5 years	28 (23.3%)
>5 years	38 (31.7%)
Brief psychiatric rating scale (BPRS)	
Mean (SD)	44.5 (12.1)
Median (minimum; maximum)	42.0 (26.0–78.0)
Brief negative symptom scale (BNSS)	
Mean (SD)	20.7 (14.3)
Median (minimum; maximum)	21.0 (8.0–55.0)
Specific levels of functioning scale (SLOF)	
Mean (SD)	182.6 (20.0)
Median (minimum; maximum)	186.0 (125.0–215.0)
World health organization disability assessment schedule 2.0 (WHODAS 2.0)	
Mean (SD)	10.7 (7.9)
Median (minimum; maximum)	9.0 (0.0–29.0)
Antipsychotic drugs	
Mean (SD)	1.2 (0.4)
Median (minimum; maximum)	1.0 (1.0–3.0)

Trends in mood and PA among participants with SSD and HC

Figure 4 illustrates the posterior distribution (panel *a*) and the estimated effect of PA (panel *b*) on mood for both groups. Among HC, we found robust evidence for a positive association between PA and subsequent mood (posterior probability = 99.9%), indicating that increased PA was followed by higher mood levels.

In contrast, the posterior probability for a positive PA → mood association in participants with SSD was 86.3%. Figure 5 illustrates the posterior distribution (panel *a*) and the estimated association between mood and PA in participants with SSD and HC (panel *b*), with posterior probabilities of 89.4% in HC and 67.8% in SSD for beta values greater than zero. The posterior prediction plots for mood and PA are shown in Figures S1 and S2 in Supplementary Material 5, respectively, and display the model's fit and the distribution of individual trajectories.

Discussion

This multimodal ecological study revealed that participants with SSD reported significantly lower daily mood than HC, but daily-level GLMM analyses detected no significant association between PA and mood in either group. To overcome these limitations, we applied a Bayesian multilevel model. This approach successfully captured dynamic, bidirectional associations between PA and mood. Among HC, higher levels of PA were associated with

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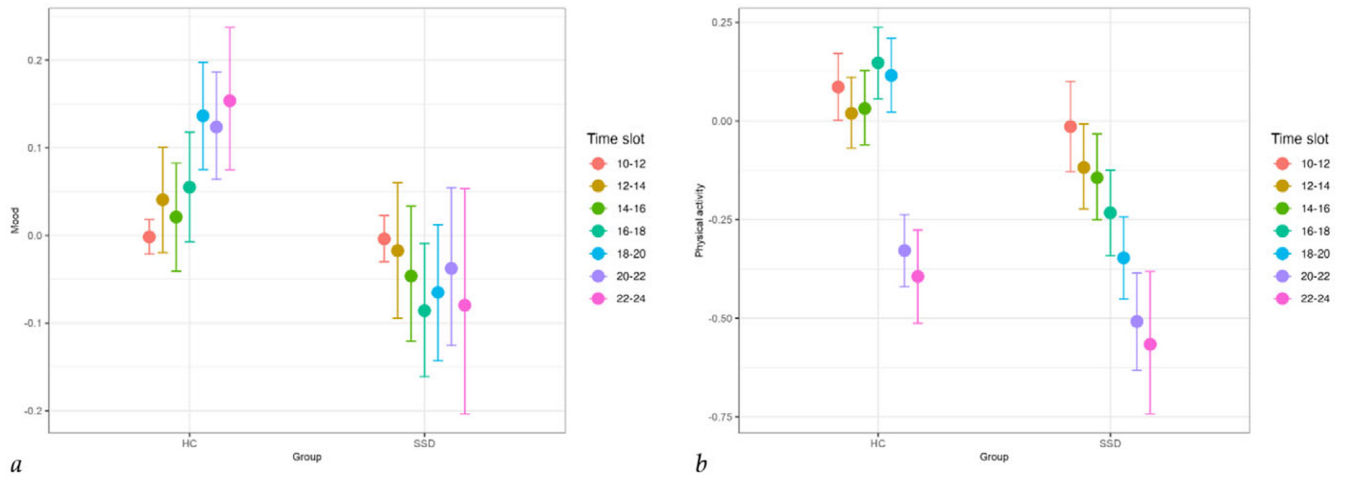


Figure 3. Mood and physical activity fluctuations in mood levels (a) and physical activity (b) according to time of the day.

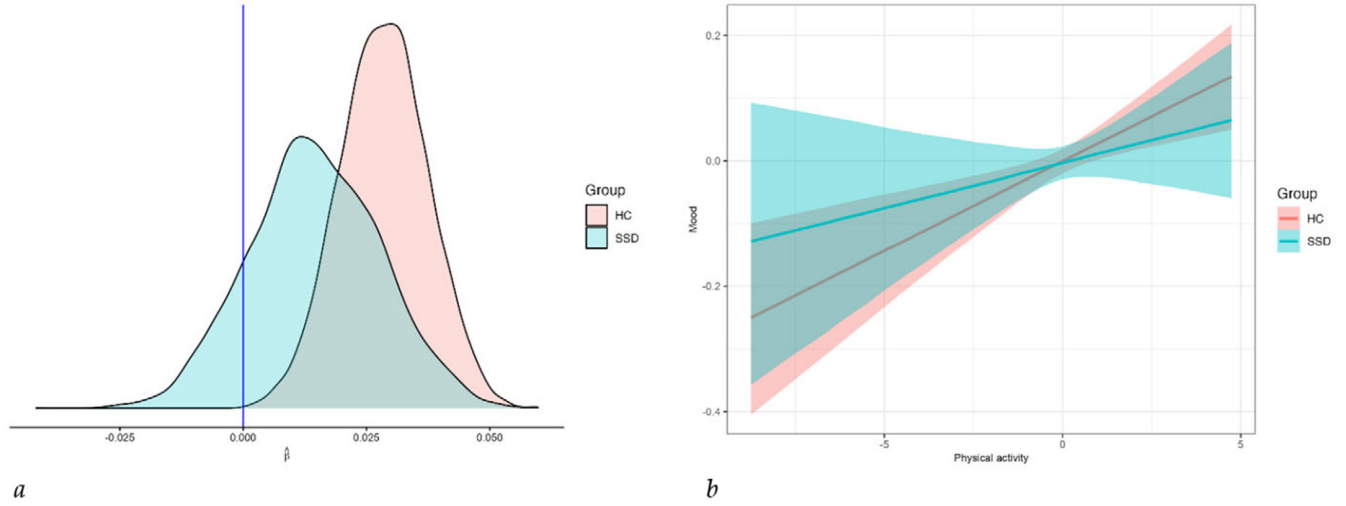


Figure 4. Posterior distribution (a) and estimated effect of physical activity on mood in SSD participants and HC (b).

subsequent higher mood, while positive mood predicted increased PA. Conversely, participants with SSD exhibited heterogeneous and inconsistent PA–mood interactions, indicating greater interindividual variability. Bayesian multilevel models with temporal lags, however, uncovered robust within-day bidirectional associations in HC (PA → mood: 99.9%; mood → PA: 89.4%), which were markedly attenuated and more heterogeneous in SSD (PA → mood: 86.3%; mood → PA: 67.8%). Diurnal analyses further showed blunted mood and activity rhythms in SSD, with the most pronounced between-group differences occurring during evening hours (6:00 PM to 12:00 AM), when mood continued to improve in HC while remaining unchanged in SSD. These temporal patterns warranted further investigation through Bayesian time-varying analyses.

These findings demonstrate that conventional daily aggregations obscure critical intraday PA–mood dynamics that Bayesian approaches successfully capture, revealing more robust bidirectional couplings in HC than in SSD. These temporal associations are compatible with bidirectional hypotheses but, given the observational design and potential unmeasured confounders (e.g., medication regimens, illness severity), do not permit causal inference. Intervention studies are needed to test whether enhancing PA–mood coupling can improve clinical outcomes in SSD. The robust temporal association between PA and subsequent mood among HC aligns with previous literature and highlights the potential of behavioral activation via PA as a universal mental health strategy (Posadzki et al., 2020). However, the attenuated and more heterogeneous associations observed in participants with SSD point to substantial interindividual variability in emotional reactivity to PA. The attenuated and heterogeneous PA → mood coupling in SSD likely reflects disorder-specific mechanisms beyond generic interindividual variability. Prominent negative symptoms such as anhedonia and avolition – core features of our sample (Table 2) – impair reward anticipation and motivational drive, disrupting the translation of physical effort into affective reinforcement (Gard et al., 2007; Millan, Fone, Steckler, & Horan, 2014). Neuroimaging

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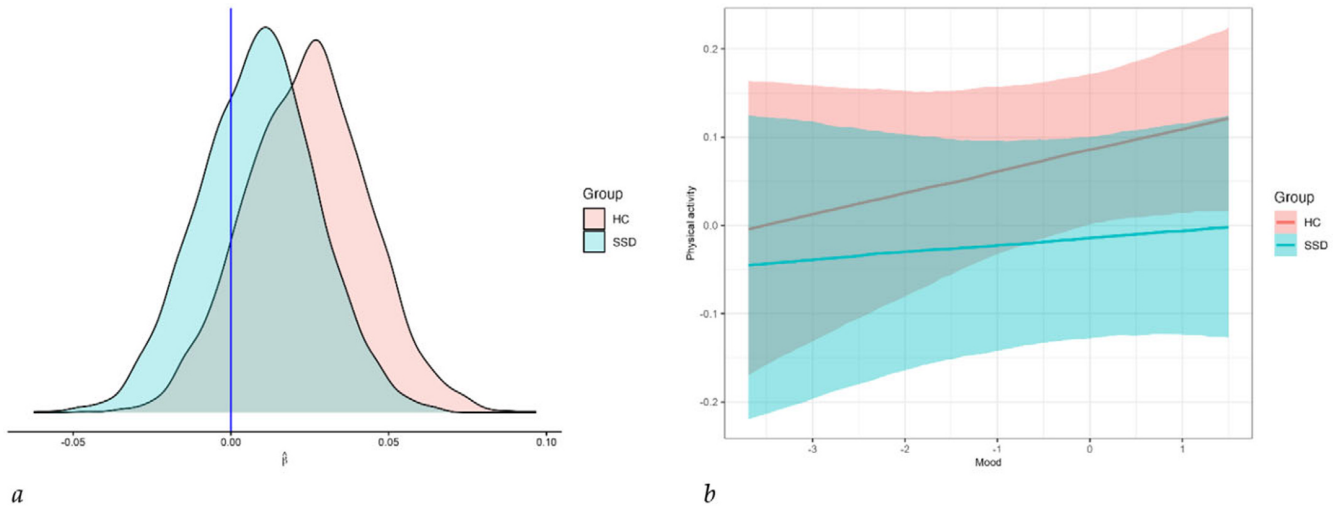


Figure 5. Posterior distribution (a) and estimated effect of mood on physical activity in SSD participants and HC (b).

evidence consistently shows ventral striatal hypoactivation during reward processing in schizophrenia, which correlates with apathy severity and reduced behavioral activation following rewarding stimuli like exercise (Kirschner et al., 2016; Segarra et al., 2016). Antipsychotic medications, used by most participants, may further blunt acute mood responses to PA through D2 receptor blockade, which dampens dopaminergic reward signaling essential for hedonic tone (Firth et al., 2019). These factors systematically weaken activity–mood linkage, explaining why Bayesian models detected robust temporal dynamics in HC but only probabilistic, variable effects in SSD – supporting targeted interventions addressing reward deficits alongside behavioral activation.

Despite these complexities, PA interventions in participants with SSD have been associated with significant mood improvements, including reduced anxiety and tension levels, decreased stress and irritability, and enhanced overall psychological well-being, underscoring the therapeutic potential of structured PA plans even in populations with diminished responsiveness (Holley, Crone, Tyson, & Lovell, 2011). The significantly lower mood reported by participants with SSD likely reflects both primary affective disturbances and secondary consequences of social isolation and sedentary behavior (Saarni et al., 2010).

Participants with SSD also demonstrated reduced PA levels and blunted diurnal variability in both mood and activity, consistent with affective flattening and diminished behavioral flexibility typical of negative symptoms such as anhedonia and avolition (D'Anna et al., 2023; Kaiser et al., 2017; Zarbo et al., 2023). While both groups exhibited a general midday peak and evening decline in mood, participants with SSD showed a significantly reduced emotional reactivity to PA fluctuations. The positive PA–mood association observed in HC was attenuated and more variable among participants with SSD, consistent with prior evidence of reduced mood reactivity and motivational impairments in this population (Dauwan et al., 2015; Firth et al., 2016; Kimhy et al., 2015). These findings highlight an important clinical insight: the relationship between mood and PA is influenced by intraday temporal variability and by potential bidirectionality. Daily aggregated analyses may overlook critical temporal dependencies inherent to dynamic psychological phenomena, even when employing sophisticated linear mixed models. Bayesian hierarchical modeling proved superior in capturing the complexity and individual variability of real-time mood–activity relationships.

Limitations

Several limitations should be acknowledged. First, while our findings suggest a beneficial role of PA in mood patterns, causal inference remains limited due to the observational nature of this study. 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. Second, although participants with a recent DSM-5 substance use disorder were excluded, residual confounding by occasional or subclinical substance use cannot be fully ruled out in outpatients. In contrast, such use is highly unlikely in residential patients given the structured, supervised setting, and all outpatients were in active treatment, which reduces (but does not eliminate) the probability of uncontrolled substance use. Third, the use of a single EMA item to index momentary mood and the reliance on one actigraphy-based PA metric may not fully capture the multidimensional nature of affect and activity patterns. Finally, the sample was recruited from Italian mental health services and residential facilities, which may limit generalizability to other health-care systems and cultural contexts.

Conclusion

Our findings highlight the need to move beyond generalized, one-size-fits-all approaches to PA in SSD. The heterogeneous emotional responses to PA observed in participants with SSD suggest the existence of distinct behavioral responsivity profiles. Identifying these profiles through real-time ecological data could inform the development of personalized, precision-based interventions. Embedding mobile sensing technologies within stepped-care models may support scalable, adaptive strategies, enabling clinicians to monitor individual trajectories and tailor interventions to maximize clinical impact.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/S0033291726105406.

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Author contribution. Dr. Giovanni de Girolamo had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Conceptualization: G.deG., C.Z., S.C., E.C.; Funding acquisition: G.deG., S.C.; Investigation: G.deG., C.Z.; Methodology & Formal analysis: S.C., M.C., D.M.; Supervision: E.C., M.C., G.deG., S.C.; Writing - original draft: E.C., M.C., S.C.; Writing - review & editing: E.C., M.C., A.M., C.Z., M.M., G.deG.

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Ethical standard. The study has been approved by the Ethical Committees (ECs) of the three main participating centers (EC of IRCCS Istituto Centro San Giovanni di Dio Fatebenefratelli, 31/07/2019; no. 211/2019; EC of Area Vasta Emilia Nord, 25/ 09/2019; no. 0025975/19), and EC of ASST of Pavia, 02/09/2019, no. 20190075685) and by the ECs of all participating sites.

Patient consent statement. All participants with SSD included in this study provided written informed consent for their participation. The consent process was conducted in accordance with ethical guidelines and regulations governing human research and was approved by the relevant ethics committees.

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References

Allison, D. B., Mentore, J. L., Heo, M., Chandler, L. P., Cappelleri, J. C., Infante, M. C., & Weiden, P. J. (1999). Antipsychotic-induced weight gain: A comprehensive research synthesis. *The American Journal of Psychiatry*, **156**(11), 1686–1696. https://doi.org/10.1176/ajp.156.11.1686

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5™* (5th ed.). American Psychiatric Publishing, Inc.

Andersen, E., Holmen, T. L., Egeland, J., Martinsen, E. W., Bigseth, T. T., Bang-Kittilsen, G., Anderssen, S. A., Hansen, B. H., & Engh, J. A. (2018). Physical activity pattern and cardiorespiratory fitness in individuals with schizophrenia compared with a population-based sample. *Schizophrenia Research*, **201**, 98–104. https://doi.org/10.1016/j.schres.2018.05.038

Arabboev, M., Begmatov, S., & Nosirov, K. (2024). Design and development of a wearable device for multi-parametric human health monitoring. *EAI Endorsed Transactions on Internet of Things*, **10**. https://doi.org/10.4108/eetiot.7025

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, **54**(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

D'Anna, G., Zarbo, C., Cardamone, G., Zamparini, M., Calza, S., Rota, M., Correll, C. U., Rocchetti, M., Starace, F., de Girolamo, G., Barlati, S., Baroncelli, A., Besana, F., Boero, M. E., Clerici, M., Di Michele, V., Durbano, F., Foia, M. G., Impicci, S., … collaborators, D. (2023). Interplay between negative symptoms, time spent doing nothing, and negative emotions in patients with schizophrenia spectrum disorders: Results from a 37-site study. *Schizophrenia*, **9**(1), 63. https://doi.org/10.1038/s41537-023-00372-x

Damme, K. S. F., Gupta, T., Ristanovic, I., Kimhy, D., Bryan, A. D., & Mittal, V. A. (2022). Exercise intervention in individuals at clinical high risk for psychosis: Benefits to fitness, symptoms, hippocampal volumes, and functional connectivity. *Schizophrenia Bulletin*, **48**(6), 1394–1405. https://doi.org/10.1093/schbul/sbac084

D'Anna, G., Zarbo, C., Cardamone, G., Zamparini, M., Calza, S., Rota, M., Correll, C. U., Rocchetti, M., Starace, F., de Girolamo, G., & DIAPASON collaborators. (2023). Interplay between negative symptoms, time spent doing nothing, and negative emotions in patients with schizophrenia spectrum disorders: Results from a 37-site study. *Schizophrenia (Heidelberg, Germany)*, **9**(1), 63. https://doi.org/10.1038/s41537-023-00372-x

Dauwan, M., Begemann, M. J. H., Heringa, S. M., & Sommer, I. E. (2015). Exercise improves clinical symptoms, quality of life, global functioning, and depression in schizophrenia: A systematic review and meta-analysis. *Schizophrenia Bulletin*, **42**(3), 588–599. https://doi.org/10.1093/schbul/sbv164

Dauwan, M., Begemann, M. J. H., Slot, M. I. E., Lee, E. H. M., Scheltens, P., & Sommer, I. E. C. (2021). Physical exercise improves quality of life, depressive symptoms, and cognition across chronic brain disorders: A transdiagnostic systematic review and meta-analysis of randomized controlled trials. *Journal of Neurology*, **268**(4), 1222–1246. https://doi.org/10.1007/s00415-019-09493-9

de Girolamo, G., Rocchetti, M., Benzi, I. M. A., Agosta, S., Casiraghi, L., Ferrari, C., De Franceschi, N., Macis, A., Pogliaghi, S., & Starace, F. (2020). DAily time use, Physical Activity, quality of care and interpersonal relationships in patients with Schizophrenia spectrum disorders (DiAPASon): An Italian

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multicentre study. *BMC Psychiatry*, **20**(1), 287. https://doi.org/10.1186/s12888-020-02588-y

Dong, M., Lu, L., Zhang, L., Zhang, Y., Ng, C. H., Ungvari, G. S., Li, G., Meng, X., Wang, G., & Xiang, Y. (2019). Quality of life in schizophrenia: A meta-analysis of comparative studies. *Psychiatric Quarterly*, **90**(3), 519–532. https://doi.org/10.1007/s11126-019-09633-4

Dunton, G. F., Liao, Y., Kawabata, K., & Intille, S. (2012). Momentary assessment of adults' physical activity and sedentary behavior: Feasibility and validity. *Frontiers in Psychology*, **3**, 260. https://doi.org/10.3389/fpsyg.2012.00260

Firth, J., Rosenbaum, S., Stubbs, B., Gorczynski, P., Yung, A. R., & Vancampfort, D. (2016). Motivating factors and barriers towards exercise in severe mental illness: A systematic review and meta-analysis. *Psychological Medicine*, **46**(14), 2869–2881. https://doi.org/10.1017/S0033291716001732

Firth, J., Siddiqi, N., Koyanagi, A., Siskind, D., Rosenbaum, S., Galletly, C., Allan, S., Caneo, C., Carney, R., Carvalho, A., Chatterton, M. L., Correll, C., Curtis, J., Gaughran, F., Heald, A., Hoare, E., Jackson, S., Kisely, S., Lovell, K., … Stubbs, B. (2019). The lancet psychiatry commission: A blueprint for protecting physical health in people with mental illness. *The Lancet. Psychiatry*, **6**(8), 675–712. https://doi.org/10.1016/S2215-0366(19)30132-4

Gabry, J., Češnovar, R., Johnson, A., & Bronder, S. (2024). Cmdstanr: R interface to 'cmdstan'. https://mc-stan.org/cmdstanr/, https://discourse.mc-stan.org

Ganguli, R. (1999). Weight gain associated with antipsychotic drugs. *The Journal of Clinical Psychiatry*, **60**(Suppl 21), 20–24.

Gard, D. E., Kring, A. M., Gard, M. G., Horan, W. P., & Green, M. F. (2007). Anhedonia in schizophrenia: Distinctions between anticipatory and consummatory pleasure. *Schizophrenia Research*, **93**(1–3), 253–260. https://doi.org/10.1016/j.schres.2007.03.008

Holley, J., Crone, D., Tyson, P., & Lovell, G. (2011). The effects of physical activity on psychological well-being for those with schizophrenia: A systematic review. *The British Journal of Clinical Psychology*, **50**(1), 84–105. https://doi.org/10.1348/014466510X496220

Kaiser, S., Lyne, J., Agartz, I., Clarke, M., Mørch-Johnsen, L., & Faerden, A. (2017). Individual negative symptoms and domains - relevance for assessment, pathomechanisms and treatment. *Schizophrenia Research*, **186**, 39–45. https://doi.org/10.1016/j.schres.2016.07.013

Kanning, M. K., Ebner-Priemer, U. W., & Schlicht, W. M. (2013). How to investigate within-subject associations between physical activity and momentary affective states in everyday life: A position statement based on a literature overview. *Frontiers in Psychology*, **4**, 187. https://doi.org/10.3389/fpsyg.2013.00187

Kimhy, D., Vakhrusheva, J., Bartels, M. N., Armstrong, H. F., Ballon, J. S., Khan, S., Chang, R. W., Hansen, M. C., Ayanruoh, L., Lister, A., Castrén, E., Smith, E. E., & Sloan, R. P. (2015). The impact of aerobic exercise on brain-derived neurotrophic factor and neurocognition in individuals with schizophrenia: A single-blind, randomized clinical trial. *Schizophrenia Bulletin*, **41**(4), 859–868. https://doi.org/10.1093/schbul/sbv022

Kirschner, M., Hager, O. M., Bischof, M., Hartmann, M. N., Kluge, A., Seifritz, E., Tobler, P. N., & Kaiser, S. (2016). Ventral striatal hypoactivation is associated with apathy but not diminished expression in patients with schizophrenia. *Journal of Psychiatry & Neuroscience*, **41**(3), 152–161. https://doi.org/10.1503/jpn.140383

McGrath, J., Saha, S., Welham, J., El Saadi, O., MacCauley, C., & Chant, D. (2004). A systematic review of the incidence of schizophrenia: The distribution of rates and the influence of sex, urbanicity, migrant status and methodology. *BMC Medicine*, **2**(1), 13. https://doi.org/10.1186/1741-7015-2-13

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**(2), 190–198. https://doi.org/10.1001/jamapsychiatry.2018.3546

Millan, M. J., Fone, K., Steckler, T., & Horan, W. P. (2014). Negative symptoms of schizophrenia: Clinical characteristics, pathophysiological substrates, experimental models and prospects for improved treatment. *European Neuropsychopharmacology*, **24**(5), 645–692. https://doi.org/10.1016/j.euroneuro.2014.03.008

Mucci, A., Galderisi, S., Merlotti, E., Rossi, A., Rocca, P., Bucci, P., Piegari, G., Chieffi, M., Vignapiano, A., Maj, M., & Italian Network for Research on Psychoses. (2015). The brief negative symptom scale (BNSS): Independent validation in a large sample of Italian patients with schizophrenia. *European Psychiatry*, **30**(5), 641–647. https://doi.org/10.1016/j.eurpsy.2015.01.014

Mucci, A., Rucci, P., Rocca, P., Bucci, P., Gibertoni, D., Merlotti, E., Galderisi, S., Maj, M., & Italian Network for Research on Psychoses. (2014). The specific level of functioning scale: Construct validity, internal consistency and factor structure in a large Italian sample of people with schizophrenia living in the community. *Schizophrenia Research*, **159**(1), 144–150. https://doi.org/10.1016/j.schres.2014.07.044

Ohi, K., Kataoka, Y., Shimada, T., Kuwata, A., Okubo, H., Kimura, K., Yasuyama, T., Uehara, T., & Kawasaki, Y. (2019). Meta-analysis of physical activity and effects of social function and quality of life on the physical activity in patients with schizophrenia. *European Archives of Psychiatry and Clinical Neuroscience*, **269**(5), 517–527. https://doi.org/10.1007/s00406-018-0903-5

Overall, J. E., & Gorham, D. R. (1962). The brief psychiatric rating scale. *Psychological Reports*, **10**(3), 799–812. https://doi.org/10.2466/pr0.1962.10.3.799

Pearce, M., Garcia, L., Abbas, A., Strain, T., Schuch, F. B., Golubic, R., Kelly, P., Khan, S., Utukuri, M., Laird, Y., Mok, A., Smith, A., Tainio, M., Brage, S., & Woodcock, J. (2022). Association between physical activity and risk of depression: A systematic review and meta-analysis. *JAMA Psychiatry*, **79**(6), 550–559. https://doi.org/10.1001/jamapsychiatry.2022.0609

Pieters, L. E., Deenik, J., Tenback, D. E., van Oort, J., & van Harten, P. N. (2021). Exploring the relationship between movement disorders and physical activity in patients with schizophrenia: An actigraphy study. *Schizophrenia Bulletin*, **47**(4), 906–914. https://doi.org/10.1093/schbul/sbab028

Posadzki, P., Pieper, D., Bajpai, R., Makaruk, H., Könsgen, N., Neuhaus, A. L., & Semwal, M. (2020). Exercise/physical activity and health outcomes: An overview of Cochrane systematic reviews. *BMC Public Health*, **20**(1), 1724. https://doi.org/10.1186/s12889-020-09855-3

Saarni, S. I., Viertiö, S., Perälä, J., Koskinen, S., Lönnqvist, J., & Suvisaari, J. (2010). Quality of life of people with schizophrenia, bipolar disorder and other psychotic disorders. *The British Journal of Psychiatry*, **197**(5), 386–394. https://doi.org/10.1192/bjp.bp.109.076489

Sala, M., Rosenfield, D., & Baldwin, A. S. (2024). Unpacking differences in post-exercise affective experiences between physically underactive and active individuals. *Journal of Behavioral Medicine*, **47**(1), 111–122. https://doi.org/10.1007/s10865-023-00442-6

Scheewe, T. W., Jörg, F., Takken, T., Deenik, J., Vancampfort, D., Backx, F. J. G., & Cahn, W. (2019). Low physical activity and cardiorespiratory fitness in people with schizophrenia: A comparison with matched healthy controls and associations with mental and physical health. *Frontiers in Psychiatry*, **10**, 87

Schneider, L. C., & Struening, E. L. (1983). SLOF: A behavioral rating scale for assessing the mentally ill. *Social Work Research & Abstracts*, **19**(3), 9–21. https://doi.org/10.1093/swra/19.3.9

Schuch, F. B., Vancampfort, D., Firth, J., Rosenbaum, S., Ward, P. B., Silva, E. S., Hallgren, M., Ponce De Leon, A., Dunn, A. L., Deslandes, A. C., Fleck, M. P., Carvalho, A. F., & Stubbs, B. (2018). Physical activity and incident depression: A meta-analysis of prospective cohort studies. *The American Journal of Psychiatry*, **175**(7), 631–648. https://doi.org/10.1176/appi.ajp.2018.17111194

Segarra, N., Metastasio, A., Ziauddeen, H., Spencer, J., Reinders, N. R., Dudas, R. B., Arrondo, G., Robbins, T. W., Clark, L., Fletcher, P. C., & Murray, G. K. (2016). Abnormal frontostriatal activity during unexpected reward receipt in depression and schizophrenia: Relationship to anhedonia. *Neuropsychopharmacology*, **41**(8), 2001–2010. https://doi.org/10.1038/npp.2015.370

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology*, **4**(1), 1–32. https://doi.org/10.1146/annurev.clinpsy.3.022806.091415

Strauss, G. P., Keller, W. R., Buchanan, R. W., Gold, J. M., Fischer, B. A., McMahon, R. P., Catalano, L. T., Culbreth, A. J., Carpenter, W. T., & Kirkpatrick, B. (2012). Next-generation negative symptom assessment for clinical trials: Validation of the brief negative symptom scale. *Schizophrenia Research*, **142**(1–3), 88–92. https://doi.org/10.1016/j.schres.2012.10.012

Stubbs, B., Williams, J., Gaughran, F., & Craig, T. (2016). How sedentary are people with psychosis? A systematic review and meta-analysis. *Schizophrenia Research*, **171**(1–3), 103–109. https://doi.org/10.1016/j.schres.2016.01.034

Ustün, T. B., Chatterji, S., Kostanjsek, N., Rehm, J., Kennedy, C., Epping-Jordan, J., Saxena, S., von Korff, M., Pull, C., & WHO/NIH Joint Project. (2010). Developing the World Health Organization disability assessment schedule

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2.0. *Bulletin of the World Health Organization*, **88**(11), 815–823. https://doi.org/10.2471/BLT.09.067231

van Hees, V. T., Gorzelniak, L., Dean León, E. C., Eder, M., Pias, M., Taherian, S., Ekelund, U., Renström, F., Franks, P. W., Horsch, A., & Brage, S. (2013). Separating movement and gravity components in an acceleration signal and implications for the assessment of human daily physical activity. *PLoS One*, **8**(4), e61691. https://doi.org/10.1371/journal.pone.0061691

Vancampfort, D., Firth, J., Schuch, F. B., Rosenbaum, S., Mugisha, J., Hallgren, M., Probst, M., Ward, P. B., Gaughran, F., De Hert, M., Carvalho, A. F., & Stubbs, B. (2017). Sedentary behavior and physical activity levels in people with schizophrenia, bipolar disorder and major depressive disorder: A global systematic review and meta-analysis. *World Psychiatry: Official Journal of the World Psychiatric Association (WPA)*, **16**(3), 308–315. https://doi.org/10.1002/wps.20458

Zanello, A., Berthoud, L., Ventura, J., & Merlo, M. C. G. (2013). The brief psychiatric rating scale (version 4.0) factorial structure and its sensitivity in the treatment of outpatients with unipolar depression. *Psychiatry Research*, **210**(2), 626–633. https://doi.org/10.1016/j.psychres.2013.07.001

Zarbo, C., Agosta, S., Casiraghi, L., De Novellis, A., Leuci, E., Paulillo, G., Rocchetti, M., Starace, F., Zamparini, M., & de Girolamo, G. (2022). Assessing adherence to and usability of experience sampling method (ESM) and actigraph in patients with schizophrenia Spectrum disorder: A mixed-method study. *Psychiatry Research*, **314**, 114675. https://doi.org/10.1016/j.psychres.2022.114675

Zarbo, C., Rota, M., Calza, S., Crouter, S. E., Ekelund, U., Barlati, S., Bussi, R., Clerici, M., Placenti, R., Paulillo, G., Pogliaghi, S., Rocchetti, M., Ruggeri, M., Starace, F., Zanolini, S., Zamparini, M., de Girolamo, G., & DiAPAson Collaborators. (2023). Ecological monitoring of physical activity, emotions and daily life activities in schizophrenia: The DiAPAson study. *BMJ Mental Health*, **26**(1), e300836. https://doi.org/10.1136/bmjment-2023-300836

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