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Association of physical symptoms with accelerometer-measured movement behaviors and functional capacity in individuals with Long COVID

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Long COVID has been linked to a decline in physical activity and functional capacity. However, it remains unclear which physical symptoms are associated with specific aspects of movement behaviors and functional capacity. We aimed to investigate the associations of fatigue, dyspnea, post-exertional malaise, myalgia, and the co-occurrence of symptoms with movement behaviors and functional capacity in individuals with Long COVID. A cross-sectional multicenter study was conducted. Questionnaires were used to assess fatigue, dyspnea, post-exertional malaise, and myalgia. Accelerometry was employed to assess sedentary time, steps per day, light physical activity, and moderate-to-vigorous physical activity. The six-minute walk test, 30-s chair stand test, and timed up and go were used to assess functional capacity. One hundred and two community-dwelling individuals who had been living with Long COVID for 15 ± 10 months participated in the study. Fatigue, post-exertional malaise, and the co-occurrence of physical symptoms showed a negative association with step count, while post-exertional malaise was also negatively associated with moderate-to-vigorous physical activity. Dyspnea showed a negative association with the functional score, including all tests. Our findings suggest that fatigue, post-exertional malaise, and the co-occurrence of physical symptoms are negatively associated with physical activity, while dyspnea is negatively associated with functional capacity in individuals with Long COVID.

Keywords Post-acute COVID-19 syndrome, Exercise, Functional status

Long COVID is characterized by the persistence of symptoms for more than 4 weeks from the onset of the acute phase of COVID-19[1], which can persist for more than 2 years[2]. Approximately 50% of individuals hospitalized with COVID-19 develop Long COVID[3]. Additionally, Long COVID is commonly reported by individuals who were not hospitalized during the acute phase of COVID-19[4]. Thus, Long COVID became a global public health issue due to its high prevalence and association with several adverse health-related outcomes, such as rehospitalization and mortality[5–7]. Individuals with Long COVID may experience several concurrent adverse physical symptoms, including fatigue, dyspnea, post-exertional malaise, and myalgia[3], making the rehabilitation process extremally challenging.

Individuals experiencing adverse physical symptoms of Long COVID may exhibit intolerance to physical effort[8–10], contributing to their reduced physical activity and functional capacity. Previous studies have indicated

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that physical symptoms of Long COVID are linked with reduced physical activity[11] and components of functional capacity, such as cardiorrespiratory fitness[12,13] and muscle strength[13,14]. However, these studies relied on self-reported methods to assess physical activity but did not consider other movement behavior components, such as sedentary time or step count and focused on specific components of functional capacity. The accelerometry method provides a comprehensive assessment of movement behaviors, including both physical activity and sedentary time[15,16]. In the same context, functional capacity may be better assessed by including various components, such as proxies for cardiorespiratory fitness, muscle strength, and dynamic balance. Therefore, this study aimed to investigate the association of adverse physical symptoms (i.e., fatigue, dyspnea, post-exertional malaise, and myalgia) with movement behaviors and various components of functional capacity in individuals with Long COVID. This exploratory study may provide indications about individuals predisposed to low physical activity, high sedentary time, and poor functional capacity among those with Long COVID. Thus, our hypothesis is that the presence of adverse physical symptoms would be associated with lower levels of physical activity, higher levels of sedentary time, and poorer functional capacity.

Material and methods

Study design

This is an exploratory cross-sectional multicenter study, which utilized baseline data from two clinical trials investigating the effects of supervised (Brazilian Registry of Clinical Trials: RBR-10y6jhrs) and semi-supervised (Brazilian Registry of Clinical Trials: RBR-45cbv3) multicomponent exercise training programs on adverse physical symptoms and functional capacity in individuals with Long COVID. Both studies received approval from the Institutional Ethics. The supervised trial was approved by ethics committee of the Federal University of Santa Catarina (CAAE 49487721.9.0000.0121). The semi-supervised trial was approved by ethics committee of the Federal University of Rio Grande do Norte (CAAE 54091521.4.1001.5537). Both protocols were in accordance with the Declaration of Helsinki. All patients signed an informed consent form to declare that they are aware and accept to participate in the study. The baseline data used for this study were collected between November 2021 and October 2023. At the beginning of the volunteer recruitment and throughout the study, there were no public policies regarding movement restrictions in Brazil.

Participants

This study included both females and males aged 18 to 75 years who were not engaged in regular physical exercise using the following question: "Have you regularly practiced any physical exercise at least twice per week in the last 3 months? This includes activities such as walking, cycling, gymnastics, sports, etc.". All participants exhibited at least one of the following adverse physical symptoms for more than 4 weeks after acute COVID-19: fatigue, dyspnea, post-exertional malaise, and myalgia. In the current study, we used the National Institute for Health and Care Excellence (NICE) guidelines to define Long COVID[1]. According to these guidelines, the term Long COVID refers to signs and symptoms that persist or develop after the acute phase of COVID-19. It encompasses both ongoing symptomatic COVID-19 (lasting from 4 to 12 weeks) and post-COVID-19 syndrome (lasting 12 weeks or more). All patients were diagnosed with COVID-19 based on RT-PCR and serology tests. Both individuals who were hospitalized and those not hospitalized during the acute phase of COVID-19 were considered for inclusion. However, individuals with severe functional limitation (grade 4 on the post-COVID functional scale)[17] and dyspnea (score 5 on the modified Medical Research Council scale)[18] were excluded from the study. In both centers, participants were recruited for a clinical trial using various methods, including lists of patients treated at the University Hospitals and Primary Health Care Units, as well as media channels such as websites, social media, TV, and radio. The data presented in this study refer to baseline assessments.

Procedures

Information on socioeconomic characteristics, previous chronic conditions, medication use, acute COVID-19, vaccination status, and adverse symptoms of Long COVID (i.e., fatigue, dyspnea, post-exertional malaise, myalgia, insomnia, memory problems, cough, anosmia/ageusia, mental health issues and hair loss) was collected through face-to-face interviews with the participants. For vaccination status, patients who had received at least one booster shot were considered fully vaccinated, while those who had received at least one dose but no booster shots were classified as partially vaccinated. For individuals who were hospitalized during the acute phase of COVID-19, details about the hospitalization, including severity length of hospital stay, oxygen therapy, Intensive Care Unit (ICU) admission, and mechanical ventilation were directly obtained from their medical records.

Exposure

Physical symptoms assessment

Fatigue was assessed using the Chalder Fatigue Scale (cutoff point: score ≥ 4) due to its widespread use and validation in measuring fatigue severity in both clinical and research settings[19]. Dyspnea was evaluated using the modified Medical Research Council scale, which is a validated tool specifically designed to measure the degree of breathlessness experienced during daily activities[18]. This scale is commonly used in respiratory research and clinical practice, making it an appropriate choice for assessing dyspnea in Long COVID[18]. The assessment of post-exertional malaise utilized the DePaul Symptom Questionnaire, a tool developed to measure this specific symptom in patients with myalgia encephalomyelitis/chronic fatigue syndrome (ME/CFS)[20]. Given the similarity in symptomatology between ME/CFS and Long COVID, the DePaul Symptom Questionnaire was used for assessing post-exertional malaise in our participants. The presence of myalgia was evaluated using the following question: "Are you experiencing any muscle pain that did not exist before the acute COVID-19? The presence of myalgia as an adverse symptom of Long COVID was made with the confirmation that there was no other plausible cause for the muscle pain. As self-reported assessment of myalgia in patients with Long COVID has been the most commonly used method to identify muscle pain in this population[21]. The co-occurrence of Long COVID physical symptoms (i.e., ≤ 1, 2, 3, and 4 symptoms) was also investigated as an exposure. This approach allows the examination of the cumulative impact of multiple symptoms on the patients' health, providing a comprehensive understanding of the symptom burden in Long COVID.

Outcome

Accelerometer-measured movement behaviors

Movement behaviors were measured using tri-axial accelerometry (Actigraph GT3X, Actigraph LLC, Pensacola, USA and ActiLife version 6.13.3.2). Participants wore the accelerometer on their right hip for seven consecutive days, removing it during sleeping periods, showering, and water-based activities. They used a logbook to record moments when they removed the accelerometer, went to sleep, and woke up. Non-wear periods were excluded from the analysis, with non-wear time defined as ≥ 90 min of consecutive zero counts and a tolerance of up to 2 min of ≥ 100 counts/min[22]. For inclusion in the final analysis, participants needed to have at least three valid weekdays of accelerometer wear time and at least one weekend day, with each day requiring ≥ 10 h of wear time. Data were collected at 90 Hz and integrated into 60-s epochs. The cut-offs to define sedentary time, light physical activity, and moderate-to-vigorous physical activity (MVPA) were: 0–99 counts/min, 100–1951 count/min and ≥ 1952 counts/min, respectively[16]. Although there is no consensus on the cut-off points for assessing movement behaviors in adults aged 18 to 75, we used the aforementioned cut-off points because they are the most commonly employed in studies with adults in the Brazilian population and are also recommended in the guidelines for accelerometer use in Brazil[23]. Together, these aspects enhance data comparability. The total period (weighted average; weekdays and weekends) was considered to calculate the volumes of sedentary time and physical activity. Step count was calculated as follows: ∑ steps/day ÷ number of valid accelerometer days. The average value of steps per day obtained during the 1-week period was considered for data analysis.

Functional capacity

The functional capacity was assessed using the following tests: (i) six-minute walk test (6MWT); (ii) 30-s chair stand test (30-s CST); (iii) timed up and go (TUG). The 6MWT was conducted in accordance with the recommendations of the American Thoracic Society[24]. Participants performed two 6MWT with a 30-min interval between them, and the best performance was considered for data analysis. For safety reasons, rating of perceived exertion (Borg scale 6–20), heart rate (Polar H10), blood pressure (OMRON, HEM-7113), and oxygen saturation (oximeter Multilaser HC261) were recorded before, during (at 2 min), and immediately after both 6MWT. Relative values were obtained from an reference equation adjusted for sex, age and body mass index (BMI)[25]. The CST and TUG were conducted following the recommendations of Rikli and Jones[26] and the relative values were obtained adjusted for age and BMI, and age, BMI and height, respectively[27]. The functional score was represented by a composite score based on the 6MWT, CST, and TUG[28]. The results of the three tests were standardized into z-scores and summed to create the functional score. The TUG z-scores were multiplied by -1, as the result is presented in seconds and is inversely associated with performance. Individuals with resting blood pressure 160/105 mmHg and/or oxygen saturation < 94% were not allowed to perform the tests for safety reasons.

Data analysis

The data distribution was assessed using the Kolmogorov–Smirnov test. Continuous variables were presented as mean ± standard deviation, while categorical variables were presented as absolute and relative frequencies (%). The independent t-test was utilized to compare movement behaviors and functional capacity between participants with and without each adverse physical symptom. To analyze the association between adverse physical symptoms and accelerometer-measured movement behaviors and functional capacity, a generalized linear model was utilized, with the group without adverse physical symptoms serving as the reference. Collinearity was examined through the Variance Inflation Factor (VIF). The analyses were adjusted for sex, age, income, multimorbidity (i.e., obesity, hypertension, diabetes, hyperlipidemia, cancer, among others)[29], ICU admission, and the study center. Obesity was defined as BMI ≥ 30 kg/m^2. Additionally, for accelerometer-measured data, adjustments were made for accelerometer wear time. Smoking was not included as a covariate due to the low number of smokers in our sample. The significance level was set at $p < 0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 27.0.

Results

A total of 102 participants were included in this study (47 ± 13 years; 58.8% females; 29.1 ± 6.0 kg/m^2; smokers/ex-smokers: 21.6%). Approximately half of them had post-secondary education (49%) and were receiving 1–3 minimum wages (51%). The majority were employed or studying (74.5%), while 11.8% were retired. The prevalence of hypertension, diabetes, and multimorbidity (≥ 2 chronic conditions) was 28.4%, 15.7%, and 21.6%, respectively. Half of the participants had mild cases (not hospitalized), 19.6% had moderate cases (requiring hospital oxygen therapy), and 30.4% had severe cases (requiring ICU admission) of acute COVID-19. Those who were hospitalized had an average length of stay of 22 ± 18 days, including 16 ± 14 days in the ICU and 13 ± 11.0 days on mechanical ventilation. On average, the participants had been experiencing adverse physical symptoms of Long COVID for 15 ± 10 months (minimum and maximum—1 to 41 month). The most prevalent adverse physical symptoms were fatigue (87.1%), dyspnea (81.2%), post-exertional malaise (58.5%), and myalgia (49.5%). Additionally, the participants reported insomnia (35.5%), memory problems (29.4%), cough (12.7%), anosmia/ageusia (10.8%), mental health issues (anxiety/depression; 7.8%), and hair loss (4.9%). Regarding vaccination status, 67.0% were fully vaccinated (Table 1).

Variable	Mean ± SD/range or n (%)
Age (years)	47.3 ± 12.8
Female, n (%)	60 (58.8)
Body Mass Index, kg/m^2	29.1 ± 6.0
Race	
White, n (%)	56 (54.9)
Black, n (%)	11 (10.8)
Others, n (%)	35 (34.3)
Education	
Elementary school, n (%)	11 (10.8)
High school, n (%)	41 (40.2)
Post-secondary, n (%)	50 (49.0)
Occupation	
Housewife, n (%)	4 (3.9)
Retired, n (%)	12 (11.8)
Non-employed, n (%)	10 (9.8)
Employ/study, n (%)	76 (74.5)
Income	
1 a 3 minimum wages, n (%)	52 (51)
3 a 5 minimum wages, n (%)	25 (24.5)
> 5 minimum wages, n (%)	25 (24.5)
Smokers/ex-smokers, n (%)	22 (21.6)
Hypertension, n (%)	29 (28.4)
Diabetes, n (%)	16 (15.7)
Multimorbidity, n (%)	22 (21.6)
Severity of COVID-19	
Mild illness, n (%)	51 (50.0)
Moderate illness, n (%)	20 (19.6)
Severe illness, n (%)	31 (30.4)
Length of stay, days	21.8 ± 18.3
ICU, days	15.9 ± 14.5
Mechanical ventilation, days	12.6 ± 11.0
Time of Long COVID, months	14.8 ± 10.2
Adverse symptoms of long COVID, n (%)	
Fatigue, n (%)	88 (87.1)
Dyspnea, n (%)	82 (81.2)
Post-exertional malaise, n (%)	55 (58.5)
Myalgia, n (%)	46 (49.5)
Insomnia, n (%)	33 (35.5)
Memory problems, n (%)	30 (29.4)
Cough, n (%)	13 (12.7)
Anosmia/ageusia, n (%)	11 (10.8)
Mental health issues (anxiety/depression), n (%)	8 (7.8)
Hair loss, n (%)	5 (4.9)
Others, n (%)	25 (24.5)
COVID-19 vaccination status	
Fully vaccinated, n (%)	57 (67.0)
Partial vaccinated, n (%)	26 (30.6)
Not vaccinated, n (%)	2 (2.4)

Table 1. Characteristics of the study participants (n = 102). SD: standard deviation. Values are expressed as mean ± standard deviation and absolute and relative frequency. Multimorbidity = ≥ two chronic diseases (i.e., obesity, hypertension, diabetes, hyperlipidemia, cancer, among others). Mild illness = who experiment any symptom and no hospitalization; moderate illness = use of hospital oxygen therapy; severe illness = admission to Intensive Care Unit (ICU). Vaccination COVID-19 status: Fully vaccinated = ≥ one booster shots; Partial vaccinated = ≥ one dose and no one booster shots.

Thirteen patients did not reach the minimum number of days of accelerometer. Two patients reported knee pain and refused to perform the 30-s CST. One participant was unable to complete 6MWT test due to dyspnea and five did not attend the assessment. Movement behaviors revealed that participants spent 10.2 ± 2.0 h/day in sedentary time, 4.8 ± 1.5 h/day in light physical activity, and 0.3 ± 0.2 h/day (113.7 ± 87.2 min/week) in MVPA; 29.5% (n = 26) met the current physical activity guidelines, i.e., at least 150 min/week of MVPA. Additionally, their average step count was 7496 ± 4309 steps/day. Regarding functional capacity, participants covered 518 ± 83 m on the 6MWT, with 72.4% classified as below the estimated value for their age, sex, and BMI. They also performed 13.3 ± 3.1 repetitions on the 30-s CST, with 86% classified as below the estimated value for their age and BMI. Additionally, they completed the TUG in 6.6 ± 1.0 s, with 100% classified as above the estimated value for their age, BMI, and height.

Table 2 details movement behaviors and functional capacity in individuals with Long COVID, categorized according to the presence of different adverse symptoms. Those with fatigue (no = 12,050 ± 5636 steps/day, n = 12; yes = 6707 ± 3570 steps/day, n = 77), post-exertional malaise (no = 9271 ± 5630 steps/day, n = 34; yes = 5993 ± 2500 steps/day, n = 49) and co-occurrence of physical symptoms (≤ 1 symptoms = 12,290 ± 5872, n = 11; 2 symptoms = 7959 ± 4236, n 22; 3 symptoms = 6109 ± 3331, n = 36; 4 symptoms = 6464 ± 2665, n = 19) exhibited a lower number of steps per day compared to their counterparts without these adverse physical symptoms ($p < 0.05$). Furthermore, individuals experiencing dyspnea performed worse on the TUG (no = 6.1 ± 0.8 s, n = 14; yes = 6.7 ± 1.0 s, n = 80) and had a lower functional score (no = 1.1 ± 1.5 a.u., n = 14; yes = 0.1 ± 1.7 a.u., n = 80) compared to those without this specific symptom ($p < 0.05$). Additionally, Supplementary Table 1 presents the movement behavior and functional capacity according to the severity of acute COVID-19. Interestingly, individuals with severe cases of acute COVID-19 exhibited a higher number of steps per day compared with mild cases and moderate cases ($p < 0.05$). There were no differences in functional capacity or other movement behavior variables between the severities of COVID-19.

Table 3 displays the adjusted associations of adverse physical symptoms and movement behaviors in individuals with Long COVID. Fatigue (β = − 3827 steps/day; 95% CI = − 6280 to − 1375), post-exertional malaise (β = − 2864 steps/day; 95% CI = − 4434 to − 1294) and co-occurrence (2 symptoms: β = − 3689 steps/day; − 6329 to − 1049; 3 symptoms: β = − 4754 steps/day; 95% CI = − 7363 to − 2145; 4 symptoms: β = − 5076 steps/day; 95%

Physical symptoms	Sedentary time (h/day)	Light PA (h/day)	MVPA (min/week)	Step count (steps/day)	6MWT (meters)	30-s CST (repetitions)	TUG (seconds)	Functional score (a.u.)
Fatigue								
No (n = 12*; 13#)	9.3 ± 1.8	5.0 ± 1.6	126.5 ± 112.7	12050 ± 5636	538.6 ± 110.5	13.5 ± 2.5	6.5 ± 1.2	0.6 ± 2.2
Yes (n = 77*; 83#)	10.4 ± 2.0	4.7 ± 1.5	112.1 ± 83.7	6707 ± 3570	514.2 ± 77.9	13.3 ± 3.2	6.6 ± 1.0	0.1 ± 1.8
p	0.087	0.610	0.600	**< 0.001**	0.326	0.857	0.721	0.366
Dyspnea								
No (n = 14*; 14#)	10.4 ± 1.4	4.2 ± 1.4	97.3 ± 90.6	7247 ± 3162	533.0 ± 99.2	14.2 ± 2.5	6.1 ± 0.8	1.1 ± 1.5
Yes (n = 72*; 80#)	10.3 ± 2.1	4.9 ± 1.5	117.9 ± 85.5	7321 ± 4180	516.3 ± 78.9	13.2 ± 3.2	6.7 ± 1.0	0.1 ± 1.7
p	0.860	0.116	0.415	0.950	0.473	0.259	**0.039**	**0.040**
Post-exertional malaise								
No (n = 34*; 36#)	10.0 ± 2.3	5.1 ± 1.7	138.1 ± 100.1	9271 ± 5630	525.2 ± 85.4	13.4 ± 3.4	6.8 ± 1.2	0.2 ± 2.0
Yes (n = 49*; 51#)	10.6 ± 1.8	4.5 ± 1.4	103.1 ± 78.6	5993 ± 2500	509.4 ± 84.3	13.3 ± 3.0	6.5 ± 1.0	0.1 ± 1.8
p	0.194	0.109	0.087	**0.001**	0.386	0.836	0.105	0.881
Myalgia								
No (n = 43*; 41#)	10.1 ± 2.1	5.1 ± 1.6	116.2 ± 95.4	8086 ± 5090	516.4 ± 80.5	13.6 ± 3.5	6.7 ± 1.1	0.3 ± 2.1
Yes (n = 39*; 43#)	10.7 ± 1.9	4.6 ± 1.5	109.9 ± 78.9	6966 ± 3365	512.3 ± 89.7	13.2 ± 3.0	6.7 ± 1.0	− 0.1 ± 1.5
p	0.187	0.115	0.750	0.249	0.822	0.587	0.866	0.434
Co-occurrence of physical symptoms								
≤ 1 symptom (n = 11*;13#)	9.4 ± 1.9	5.1 ± 1.6	149.2 ± 125.1	12,290 ± 5872	525.5 ± 109.7	13.9 ± 3.1	6.6 ± 1.1	0.5 ± 2.3
2 symptoms (n = 23*;22#)	9.7 ± 2.1	5.0 ± 1.7	111.0 ± 79.3	7959 ± 4236†	544.1 ± 68.1	13.2 ± 2.9	6.5 ± 1.2	0.4 ± 2.0
3 symptoms (n = 36*;41#)	10.5 ± 1.9	4.7 ± 1.5	103.4 ± 86.4	6109 ± 3331†	516.8 ± 60.1	13.3 ± 3.5	6.6 ± 1.0	0.3 ± 1.7
4 symptoms (n = 19*;22#)	10.9 ± 1.8	4.6 ± 1.5	116.8 ± 74.6	6464 ± 2665†	488.7 ± 106.7	13.0 ± 2.8	6.7 ± 1.0	− 0.5 ± 1.5
p	0.121	0.672	0.514	**< 0.001**	0.175	0.871	0.983	0.283

Table 2. Movement behaviors and functional capacity of individuals with Long COVID, categorized according to the presence of different adverse symptoms. PA: physical activity; MVPA: moderate-to-vigorous physical activity; 6MWT: six-minute walk test; CST: chair stand test; TUG: timed up and go. Values are expressed as mean ± standard deviation. Bold values indicate $p < 0.05$. †Indicate difference with ≤ 1symptoms. Functional score was calculated by summing the z-scores of all tests, adjusted for sex. *Individuals with movement behaviors data; #Individuals with functional capacity data.

Physical symptoms	Sedentary time (h/day)		Light PA (h/day)		MVPA (min/week)		Step Count (steps/day)	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
Fatigue								
No (n = 12)	Reference		Reference		Reference		Reference	
Yes (n = 77)	0.5 (− 0.5; 1.5)	0.314	− 0.8 (− 1.7; 0.2)	0.100	− 19.9 (− 73.0; 39.2)	0.554	− 3827 (− 6280; − 1375)	**0.002**
Dyspnea								
No (n = 14)	Reference		Reference		Reference		Reference	
Yes (n = 72)	− 0.3 (− 1.2; 0.5)	0.468	0.3 (− 0.5; 1.1)	0.419	19.1 (− 28.5; 66.6)	0.432	649 (− 1416; 2714)	0.538
Post-exertional malaise								
No (n = 34)	Reference		Reference		Reference		Reference	
Yes (n = 49)	0.4 (− 0.3; 1.0)	0.273	− 0.5 (− 1.1; 0.1)	0.121	− 41.4 (− 78.2; − 4.6)	**0.027**	− 2864 (− 4434; − 1294)	**< 0.001**
Myalgia								
No (n = 43)	Reference		Reference		Reference		Reference	
Yes (n = 39)	0.6 (− 0.4; 1.3)	0.067	− 0.5 (− 1.1; 0.1)	0.125	− 0.7 (− 37.4; 35.9)	0.969	− 1226 (− 2780; 328)	0.122
Co-occurrence of physical symptoms								
≤ 1 symptom (n = 11)	Reference		Reference		Reference		Reference	
2 symptoms (n = 26)	0.6 (− 0.5; 1.7)	0.270	− 0.8 (− 1.8; 0.3)	0.137	− 52.6 (− 114.1; 8.9)	0.094	− 3689 (− 6329; − 1049)	**0.006**
3 symptoms (n = 36)	0.8 (− 0.3; 1.9)	0.137	− 1.2 (− 2.2; − 0.2)	**0.025**	− 56.0 (− 116.4; 4.4)	0.069	− 4754 (− 7363; − 2145)	**< 0.001**
4 symptoms (n = 19)	1.1 (− 0.0; 2.3)	0.053	− 1.2 (− 2.3; − 0.1)	**0.026**	− 42.2 (− 105.3; 21.0)	0.191	− 5076 (− 7807; − 2345)	**< 0.001**

Table 3. Adjusted associations between adverse physical symptoms and movement behaviors in individuals with Long COVID. PA: physical activity; MVPA: moderate-to-vigorous physical activity. Values are expressed in coefficient estimates (β) and its 95% confidence interval (CI). Bold values indicate p < 0.05. The analyses were adjusted for age, sex, income, multimorbidity (i.e., obesity, hypertension, diabetes, hyperlipidemia, cancer, among others), length of stay in the ICU, study center, and accelerometer wear time. VIF < 3.5 for all variables.

CI = − 7807 to − 2345) showed a negative association with the number of steps per day (p < 0.05), while post-exertional malaise (β = − 41.4 min/week; 95% CI = − 78.2 to − 4.6) was also negatively associated with MVPA (p < 0.05). No association was found between dyspnea and myalgia with sedentary time, light PA, MVPA or steps count (p > 0.05).

Table 4 displays the adjusted associations of adverse physical symptoms and functional capacity in individuals with Long COVID. Only dyspnea (β = − 0.1 a.u.; 95% CI = − 1.0 to − 0.6) showed a negative association with the functional score (p < 0.05) and (β = 0.5 s; 95% CI = < 0,0 to 1.0) a positive association with TUG. Finally, no association was found between fatigue, post-exertional malaise and myalgia with 6MWT, 30-s CST and TUG (p > 0.05).

Discussion

The main findings of this study were: (i) fatigue and post-exertional malaise were negatively associated with step count; (ii) post-exertional malaise was negatively associated with MVPA; (iii) dyspnea was negatively associated with a total functional score, but none of the adverse physical symptoms were associated with specific functional tests (i.e., 6MWT, 30-s CST, and TUG).

The number of steps per day was ~ 4000 lower in individuals experiencing fatigue. A cohort study revealed that individuals with Long COVID experiencing fatigue had a higher likelihood of being physically inactive 6–11 months following hospitalization[30]. In other clinical populations, fatigue has also been associated with reduced accelerometer-measured physical activity[31,32], reinforcing its negative impact on this aspect of movement behavior. Considering that 87% of our participants were experiencing fatigue, and previous studies have demonstrated that this adverse physical symptom is highly prevalent[33,34], our data suggest that individuals with Long COVID are predisposed to the deleterious health consequences of physical inactivity. In our study, 79.5% of the participants did not meet the current physical activity guidelines.

Furthermore, individuals who reported post-exercise malaise demonstrated ~ 3000 fewer steps per day and ~ 41 fewer minutes per week in MVPA. Post-exertional malaise is characterized by a worsening of symptoms that occurs after physical or mental activities, including fatigue, pain, and/or cognitive function[20]. In our study, 50% of the participants reported experiencing post-exercise malaise. Despite the limitations of a cross-sectional design in establishing causality, the observation that light physical activity levels were comparable between participants with and without this symptom implies that individuals can reduce their MVPA as a protective action against the onset of post-exercise malaise. Our findings are consistent with previous studies[8,9] that have demonstrated an association between post-exertional malaise and lower self-reported physical activity levels in individuals with Long COVID.

No significant association was observed between fatigue, post-exertional malaise, and sedentary time, light physical activity, and physical function. All patients were able to perform exercise tests, except for one case that was unable to complete the 6MWT and two patients reported knee pain and refused to perform the 30-s CST. These data suggest that symptomatology does not influence the performance of various exercise tests, consistent with previous literature[35,36]. However, this finding highlights the potential lack of sensitivity of functional tests

Physical symptoms	6MWT (meters)		30-s CST (repetitions)		TUG (seconds)		Functional score (a.u.)	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
Fatigue								
No (n = 13)	Reference		Reference		Reference		Reference	
Yes (n = 83)	11.6 (− 38.7; 61.9)	0.651	0.6 (− 1.4; 2.5)	0.560	− 0.2 (− 0.9; 0.4)	0.541	< 0.0 (− 1.1; 1.2)	0.946
Dyspnea								
No (n = 15)	Reference		Reference		Reference		Reference	
Yes (n = 80)	− 11.8 (− 54.4; 30.8)	0.587	− 0.6 (− 2.3; 1.1)	0.511	0.5 (< 0,0; 1.0)	**0.049**	− 1.0 (− 1.9; 0.0)	**0.042**
Post-exertional malaise								
No (n = 36)	Reference		Reference		Reference		Reference	
Yes (n = 51)	− 5.3 (− 39.4; 28.7)	0.759	− 0.2 (− 1.6; 1.1)	0.717	− 0.4 (− 0.8; 0.1)	0.086	− 0.1 (− 1.0; 0.6)	0.718
Myalgia								
No (n = 41)	Reference		Reference		Reference		Reference	
Yes (n = 43)	− 1.4 (− 35.1; 32.3)	0.936	− 0.2 (− 1.5; 1.1)	0.756	− 0.1 (− 0.5; 0.3)	0.722	− 0.1 (− 0.9; 0.6)	0.763
Co-occurrence of physical symptoms								
≤ 1 symptom (n = 13)	Reference		Reference		Reference		Reference	
2 symptoms (n = 22)	40.6 (− 12.7; 93.8)	0.155	− 0.1 (− 2.2; 2.1)	0.997	− 0.4 (− 1.1; 0.3)	0.272	0.4 (− 0.8; 1.6)	0.547
3 symptoms (n = 41)	38.6 (− 14.3; 91.4)	0.189	0.3 (− 1.9; 2.4)	0.717	− 0.4 (− 1.1; 0.3)	0.165	0.4 (− 0.8; 1.6)	0.487
4 symptoms (n = 22)	− 5.0 (− 59.4; 49.3)	0.761	− 0.2 (− 2.5; 2.0)	0.994	− 0.2 (− 1.0; 0.5)	0.330	− 0.4 (− 1.7; 0.9)	0.624

Table 4. Adjusted associations between adverse physical symptoms and functional capacity in individuals with Long COVID. 6MWT: six-minute walk test; CST: chair stand test; TUG: timed up and go; a.u.: arbitrary units. Values are expressed in coefficient estimates (β) and its 95% confidence interval (CI). Functional score was calculated by summing the z-scores of all tests, adjusted for sex. Bold values indicate $p < 0.05$. The analyses were adjusted for age, sex, income, multimorbidity (i.e., BMI, hypertension, diabetes, hyperlipidemia, cancer, among others) length of stay in the ICU and study center. VIF < 3.5 for all variable.

in identifying the consequences of Long COVID symptoms on daily activities, as these effects were only evident when measured through physical activity monitors.

Regarding functional capacity, we did not observe significant associations of most adverse physical symptoms with 6MWT, 30-s CST, and TUG. However, individuals experiencing dyspnea demonstrated a lower functional score, which is a composite metric aggregating the performances of all tests. In our study, almost all participants were assessed after 6 months of acute COVID-19. Thus, our findings suggest that the persistence of dyspnea may have a negative impact on the functional capacity in individuals with Long COVID who have been living with this condition for at least 6 months. The functional score included tests that are proxies of cardiorespiratory fitness, lower-limb muscle strength, and agility/dynamic balance[26,37], providing a comprehensive view of the relationship between adverse physical symptoms and functional capacity in individuals with Long COVID.

Study limitations

This exploratory study has limitations. The cross-sectional design precludes the establishment of causality. The symptoms of Long COVID can fluctuate over time, and the participants were assessed at a single time point[1]. The sample size may be underpowered for some analyses, particularly due to the limited number of participants without fatigue and dyspnea. We excluded individuals with severe functional limitations and dyspnea for safety reasons. Including these patients might have strengthened the associations between adverse physical symptoms of Long COVID and movement behavior/functional capacity. Additionally, patients who cannot live alone due to severe functional limitations[17] or who struggle with leaving the house or dressing due to shortness of breath[18] would face significant challenges in participating in the research procedures. We also excluded individuals who engage in regular physical exercise. Lastly, our sampling was voluntary and non-probabilistic. Therefore, our results should be interpreted with caution. However, the novel results of this study may provide valuable clinical insights into the relationship between adverse physical symptoms, movement behaviors, and functional capacity in individuals with Long COVID.

In conclusion, fatigue and post-exertional malaise were negatively associated with physical activity, while dyspnea showed a negative association with functional capacity in individuals with Long COVID. These findings should be taken into consideration in rehabilitation programs delivered for this population.

Data availability

The raw data is available at supplementary material two.

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Author contributions
F.J.R-S. and Y.A.F. were a major contributor in developing the methods and writing the manuscript. L.M.G., J.C.B.L.P., R.S.D. and A.M.G. helped to plan the research, validate the methods and draft the manuscript. F.D.A, C.E.S.G. and J.C.B.L.P. helped with data acquisition. C.R.R, R.M.R-T and E.C.C. supervised the research and helped to draft the manuscript.

Competing interests
The authors declare no competing interests.

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