2024, Retos, 54, 151-158

Variability of gross and fine motor control in different tasks in fibromyalgia patients
Variabilidad del control motor grueso y fino en diferentes tareas en pacientes con fibromialgia

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Abstract. Fibromyalgia (FM) is normally defined as a widespread pain syndrome or disease that presents disturbances in gross and fine motor control. As a gross motor control skill, gait requires coordination, balance, and muscle strength, and it could be an essential factor for FM patients to perform daily activities. Measuring the spatial and temporal gait parameters or gait variability has been used to assess motor pathologies and identify gait disorders. The Lyapunov exponent is a non-linear measure of variability, which quantifies the ability that the system has to attenuate small perturbances, indicating that there might be a relationship between balance and spatiotemporal gait parameters. This technique has already been used for gait analysis and could be used in fine and gross daily tasks, such as the finger tapping test (FTT) or the sit-and-stand test. Inertial Measurement Units have also been used to analyze gross motor control, namely in gait variability. So, the aim of this study is to analyze and compare the variability of gross and fine motor movements between patients with FM and a control group. The sample included 20 female participants, 10 with FM and 10 without (46.150 ± 12.835 years old). To analyze gross motricity, participants were asked to perform the gait task for two minutes and the 30-second chair sit-and-stand test; and to analyze fine motor control, they were asked to perform six trials of FTT test with both hands. To collect the data, an inertial sensor (IMU) was used. FM patients showed a more irregular pattern of linear acceleration peaks than controls in both tasks. Lyapunov values in FM patients show greater instability and variability in the anteroposterior and vertical movements for gait analysis and present significantly higher variability in the anteroposterior movements when performing the sit and stand task and the finger tapping test.
Keywords: Fibromyalgia; Gross Motor Control; Gait; Sit and Stand; Variability; Lyapunov; IMU

Resumen. La fibromialgia (FM) se define normalmente como un síndrome o enfermedad de dolor generalizado que presenta alteraciones en el control motor grueso y fino. Como habilidad de control motor grueso, la marcha requiere coordinación, equilibrio y fuerza muscular, y podría ser un factor esencial para que los pacientes con FM realicen sus actividades diarias. La medición de los parámetros espaciales y temporales de la marcha o la variabilidad de la marcha se ha utilizado para evaluar patologías motoras e identificar trastornos de la marcha. El exponente de Lyapunov es una medida no lineal de la variabilidad, que cuantifica la capacidad que tiene el sistema para atenuar pequeñas perturbaciones, y podría existir una relación entre el equilibrio y los parámetros espaciotemporales de la marcha. Esta técnica ya se ha utilizado para el análisis de la marcha y podría emplearse en tareas cotidianas finas y gruesas, como la prueba de golpeteo con los dedos (FTT) o la prueba de sentado y de pie. Las unidades de medición inercial también se han utilizado para analizar el control motor grueso, concretamente en la variabilidad de la marcha. Así pues, el objetivo de este estudio es analizar y comparar la variabilidad de los movimientos motores gruesos y finos entre pacientes con FM y un grupo de control. La muestra incluyó 20 participantes femeninas, 10 con FM y 10 sin FM (46,150 ± 12,835 años). Para analizar la motricidad gruesa, se pidió a los participantes que realizaran la tarea de andar durante dos minutos y la prueba de sentarse y levantarse en silla durante 30 segundos; y para analizar el control motor fino, se les pidió que realizaran seis ensayos de la prueba FTT con ambas manos. Para recoger los datos se utilizó un sensor inercial (IMU). Los pacientes con FM mostraron un patrón más irregular de picos de aceleración lineal que los controles en ambas tareas. Los valores de Lyapunov en pacientes con FM muestran una mayor inestabilidad y variabilidad en los movimientos anteroposteriores y verticales para el análisis de la marcha y presentan una variabilidad significativamente mayor en los movimientos anteroposteriores al realizar la tarea de sentarse y levantarse y la prueba de golpeteo con los dedos.
Palabras clave: Fibromialgia; Control motor grueso; Marcha; Sentarse y levantarse; Variabilidad; Lyapunov; IMU

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Introduction

Fibromyalgia (FM) is normally defined as a non-inflammatory widespread pain syndrome or disease with central sensitization mechanisms (Carrasco-Vega, Ruiz-Muñoz, Cuesta-Vargas, Romero-Galisteo, & González-Sánchez, 2022) that can cause increased sensitivity to nonpainful stimuli. Central sensitization is commonly seen in chronic diseases and can be defined as a central pain processing dysfunction (Cagnie et al., 2014; Carrasco-Vega et al., 2022; Eken et al., 2018; Nijs et al., 2012). In addition to widespread pain, Fibromyalgia is also associated with a number of other psychosomatic symptoms (ACSM, 2021). Functional impairment is also present in FM, and it might be related to disturbances in fine and gross motor control (Rasouli, Fors, Borchgrevink, Öhberg, & Stensdotter, 2017). FM patients also reveal low cardiac capacity and loss of muscle function, as well as low physical and functional performance (ACSM, 2021; Carrasco-Vega et al., 2022). These deficits are usually caused by widespread chronic pain that limits the patient's ability to carry out their daily activities, resulting in a progressive decline (ACSM, 2021; Carrasco-Vega et al., 2022; Cerón-Lorente et al., 2018). Previous research indicates that the impact of fibromyalgia symptoms, such as pain, stiffness, and muscle fatigue, may influence the ability to maintain balance and postural control (Del-Moral-García et al., 2020). Postural control, when affected, leads to greater risk and frequency of falls (Cerón-Lorente et al., 2018; Del-Moral-García et al., 2020). Balance tasks, such as gait, rely heavily on somatosensory information from muscles that can be disrupted by muscle soreness (Del-Moral-García et al., 2020; Jones, Horak, Winters-Stone, Irvine, & Bennett, 2009). Therefore, early disease management based on patient education, physical activity, function, and movement might be important (Carrasco-Vega et al., 2022; Del-Moral-García et al., 2020).

According to Carrasco-Vega et al. (2022) "The step or gait can be considered one of the locomotor gestures with greater clinical relevance". Because gait is a movement that requires a series of motor skills and capacities, such as coordination, dynamic and semi-static balance, endurance, and muscle strength, it could be an important factor in the individual's ability to maintain independence and manage to perform daily activities.

Previous research by Heredia-Jimenez, Orantes-Gonzalez, and Soto-Hermoso (2016) reports that measuring the spatial and temporal gait parameters has been used to assess motor pathologies and identify gait disorders, being considered highly clinically relevant. There are standard values for these gait parameters, specific to different age groups, which make it possible to detect any potential pathologies (De Frutos et al., 2022). These measurements of spatiotemporal parameters quantify gait variability. According to Rantalainen, Karavirta, Pirkola, Rantanen, and Linnamo (2020) "Gait variability refers to the phenomenon that each step/stride differs slightly from the next one." In patients with Fibromyalgia, this analysis of gait variability has proved to be effective in providing important information about these patients' physical and cognitive states (Heredia-Jimenez et al., 2016).

Inertial Measurement Units or Inertial Sensors have been applied in the analysis of gait variability, as, in addition to being more affordable, they have allowed a potential improvement in the ecological validity of gait data (Rantalainen et al., 2020). Inertial sensors allow the collection of tridimensional (3D) angular velocity and linear acceleration data throughout the entire task and in a more practical way. To analyze gait variability, linear acceleration data is better for this purpose as it is more sensitive to oscillations and subtle changes in human movement during the entire gait task (Camomilla, Bergamini, Fantozzi, & Vannozzi, 2018).

Since body stability can be characterized as the capacity of the individual's motor system to maintain its original state when under the influence of disturbances, the Lyapunov exponent is defined as a measure to quantify this capacity that the system has to mitigate small perturbances. This exponent measure the system's sensitivity to perturbances through the quantification of divergence of trajectories in the state space. So, higher Lyapunov values represent a higher divergence of trajectories, which results in greater instability of the system (Dingwell & Marin, 2006; Heredia-Jimenez et al., 2016).

Lewek, Bradley, Wutzke, and Zinder (2014) refer that there might be a significant relationship between balance measures and spatiotemporal gait parameters. Therefore, the Lyapunov exponent might be a good measure to quantify gait variability. Because gait is a functional and daily movement that requires a series of motor skills, the movement of sitting and standing up from a chair was also applied in this study as another functional movement that can be analyzed by measuring variability.

Sommervoll, Ettema, and Vereijken (2011) refer that more demanding and high-speed tasks tend to show higher variability values in older adults when compared to younger adults and that the variability values depend not only on age but also on task characteristics. One of these speed-dominated tasks is the finger tapping test. The finger tapping test is usually used to assess neurodegenerative diseases (Roalf et al., 2018) but has also been used in fibromyalgia patients to understand what happens in the motor cortex when these fine motor movements are performed (Eleonora Gentile et al., 2020; E. Gentile, Ricci, Delussi, Brighina, & de Tommaso, 2019), and for this reason, the variability analysis in FTT might be able to provide important information about fibromyalgia patients.

According to these statements, the aims of this study were: a) to verify if variability, through the Lyapunov measure in gross motor movements, is higher in patients with FM, when compared to the control group and b) to verify if variability, through Lyapunov measure, is higher in fine motor movements, such as finger tapping in patients with FM.

Methods

Sample

The sample for this study was composed of 20 female participants (Table 1), 10 diagnosed with FM according to American College of Rheumatology standards (ACR., 2022) and by a qualified clinician (experimental group), and 10 participants without FM, selected according to their age, gender, and physical activity levels, in order to present similar characteristics to those in the experimental group (control group). All participants signed an informed consent, which has been approved by the Ethics Committee of the Polytechnic Institute of Santarém (Nº 2A-2022 ESDRM), to allow them to participate in this study.

Table 1.
Sample Characterization

Group	Age		Height		Weight	
	Mean	SD	Mean	SD	Mean	SD
Fibromyalgia	46.400	12.714	162.900	5.243	63.000	10.536
Control	45.900	12.950	157.800	5.671	60.700	5.675
Total	46.150	12.835	160.350	6.027	61.850	8.540

SD – standard deviation

Procedures

To analyze gross motor skills, participants were asked to perform the gait task and the 30-second chair sit-and-stand test (Rikli, 2013). To collect the data, an inertial sensor (IMU) (Movesense HR+, Movesense Ltd, Finland) was used to collect tridimensional (3D) linear acceleration and angular velocity, and it was placed on the right leg, above the malleolus of the fibula, while performing the gait task

2024, Retos, 54, 151-158

for 2 minutes on a straight ground and at a comfortable speed for the practitioner (Figure 1) and, on the right thigh, above the knee, during the 30-second chair sit-and-stand test (Figure 2). This last test was carried out according to the Senior Fitness Test Battery (Rikli, 2013), test widely applied to elderly (e.g., Matos-Duarte, Martínez De Haro, Sanz Arribas, and Berlanga (2021); Pucci, Neves, Santana, Neves, and Saavedra (2021) as well as to less conditioned or frail populations (e.g., Medrano Ureña, Ortega Ruiz, and Benítez Sillero (2022). The practitioners had to stand and sit on the chair as many times as possible for 30 seconds while keeping their arms crossed over the chest. The chair used for this test was the same for all practitioners.

According to the position of the IMU in both tasks, the movements that represent the X, Y, and Z axes are the anteroposterior, vertical and mediolateral movements, respectively (Figure 1). The inertial sensor was used to collect linear acceleration and angular velocity. Data was sent to the computer via Wi-fi and was recorded in an excel file (.xls).

For fine motor control, the finger tapping test was applied (Christianson, 2004). The practitioners were asked to touch the surface with the index finger at a maximum speed for 10 seconds, six trials for each hand. An inertial sensor (MEMS model MPU9250) was attached to a rubber finger, allowing the collection of tridimensional linear acceleration and angular velocity data. These data were sent to the computer via Bluetooth, received via a serial terminal (connection endpoint) (YAT) (Klay, 2021), and recorded in a text file (.txt).

Then the excel files and the text files were sent to MATLAB (MATLAB, 2021) and SPSS (IBM, 2021) for data processing.

Figure 1. IMU Position in Gait Task

Figure 2. IMU Position in Sit and Stand Task

Data Treatment and Statistical Analysis

The tridimensional acceleration data of all tasks were collected from the inertial sensor and treated in a customized MATLAB (MATLAB, 2021) routine, in which this acceleration was filtered by a Butterworth digital filter of order 4 with a cutoff frequency of 30Hz (Figure 3). In Figure 3, the raw data are represented by the dashed lines, and the filtered data corresponds to the colored lines for all movement axis.

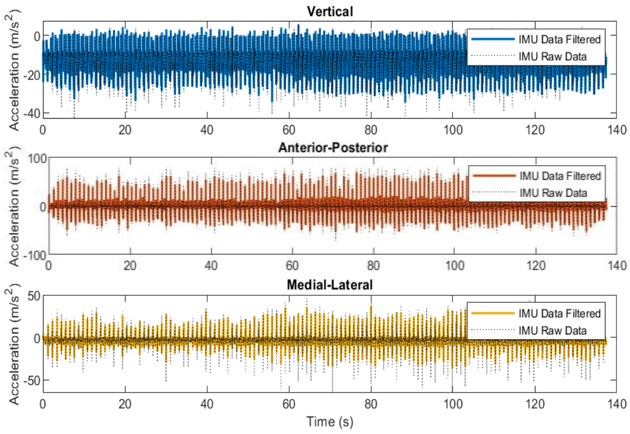

Figure 3. Differences between Raw (black line) and filtered data (color line), in gait task

For the calculation of Lyapunov, a routine based on Wolf's algorithms (Raffalt, 2020) was used for all tasks.

For gross motor control, in the statistical analysis, normality was tested with the Shapiro-Wilk test, which was not assumed for all variables.

Accordingly, for those which had normality, a T-Test was applied for independent samples for comparisons between groups, and for variables without normality, the U-Mann Whitney was used. For fine motor control, normality was tested and was not assumed for any of the variables. The effect sizes were calculated using Cohen's d algorithm, according to Fields (2018).

Results

Gross Motor Control

Some results of the various stages of data treatment are presented below. Figure 4 and Figure 5 represent the linear acceleration peaks for vertical, anteroposterior and mediolateral movements during gait task in practitioners belonging to the control and fibromyalgia group, respectively.

Matlab was able to detect the maximum amplitude of the linear acceleration (red dots and green dots). Therefore, the data presented within the maximum amplitude of acceleration or between the acceleration peaks (red and green dots), correspond to the oscillations of vertical, anteroposterior, and mediolateral movements in both groups during gait task.

2024, Retos, 54, 151-158

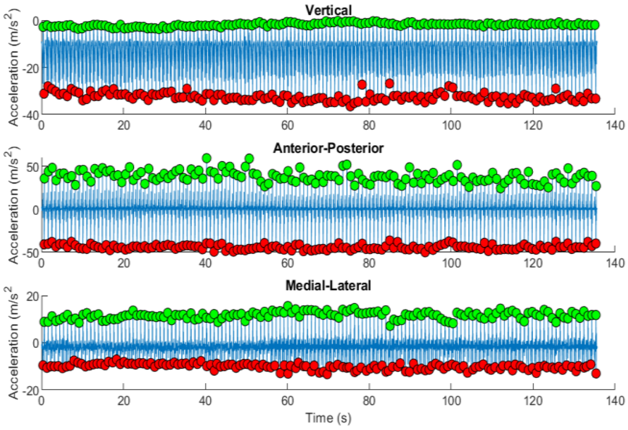

Figure 4. Tridimensional linear acceleration for the control group in gait analysis

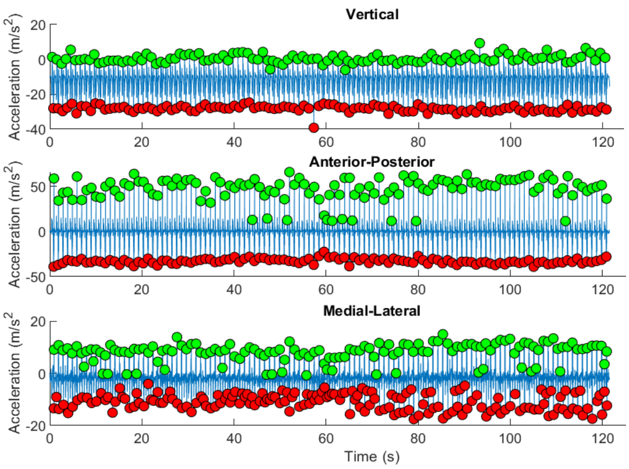

Figure 5. Tridimensional linear acceleration for fibromyalgia group in gait analysis

Comparing both plots, the fibromyalgia group presents a greater irregularity in the pattern of the acceleration peaks than the control group, mainly in the anteroposterior and mediolateral movements. The same results are presented for the sit and stand task. Figure 6 and Figure 7 represent the linear acceleration peaks (red and green dots) for vertical, anteroposterior, and mediolateral movements during sit and stand task in control and fibromyalgia practitioners, respectively. Matlab was also able to detect the maximum amplitude of the linear acceleration (red dots and green dots) for sit and stand task. The data presented within the maximum amplitude of acceleration or between the acceleration peaks correspond to the oscillations of all tridimensional movements in both groups during sit and stand task.

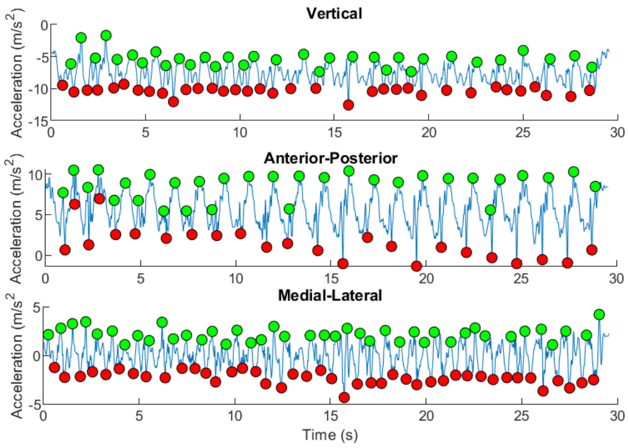

Figure 6. Tridimensional linear acceleration for the control group in sit and stand analysis

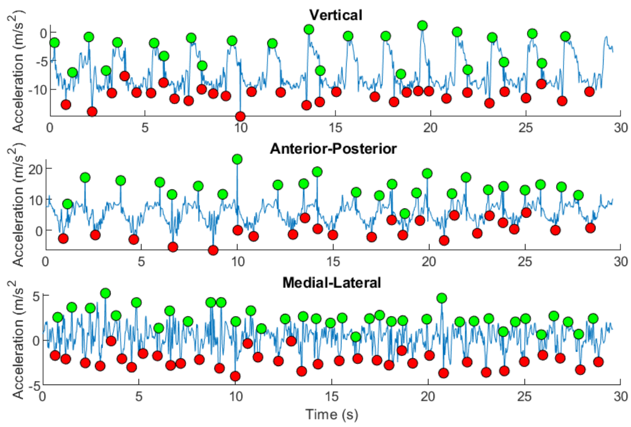

Figure 7. Tridimensional linear acceleration for fibromyalgia group in sit and stand analysis

Fibromyalgia group has a higher maximum amplitude of acceleration in the anteroposterior movements (0 to 20), compared to the controls, and a greater irregularity in the pattern of the acceleration peaks in all axes of movement.

In

Table 2, the values for the statistical analysis and significance level for the variables of mediolateral, anteroposterior and vertical Lyapunov values are presented per task and between groups.

Table 2.
Statistical analysis in tridimensional acceleration Lyapunov values in gait and sit and stand tasks between groups. In bold are the variables with significant differences.

Task/Group		Fibromyalgia		Control		Test Statistics			
		Mean	SD	Mean	SD	U	t	Sig.	Effect Size
Gait	LyE_ML	8.812	3.084	7.700	1.570	36.000	-	0.290	
	LyE_AP	7.298	2.791	6.352	2.637	37.000	-	0.353	
	LyE_Vert	13.564	5.174	16.911	5.089	28.000	-	0.096	
Sit & Stand	LyE_ML	9.450	2.896	10.496	3.542	45.000	-	0.705	
	LyE_AP	10.746	3.731	6.560	4.134	-	2.377	0.029	0.489
	LyE_Vert	9.974	2.767	10.514	2.422	39.000	-	0.405	

LyE ML – Lyapunov mediolateral; LyE AP – Lyapunov anteroposterior; LyE Vert – Lyapunov Vertical; SD – standard deviation; U – U Mann Whitney; t – T test; Sig. – significance Level

2024, Retos, 54, 151-158

In gait task, although FM participants present higher Lyapunov values in the mediolateral and anteroposterior axes than the controls and lower values in the vertical axis, there are no significant differences between groups. However, in Sit and Stand task, there are significant differences in the anteroposterior Lyapunov values between groups (t=2.377; p=0.029). The effect size was calculated for the variables with significant differences, showing a medium effect (Fields, 2018).

Fine Motor Control

The results (Table 3) below correspond to the FTT Lyapunov values for each group and hand between trials. Considering that the FTT is a precise and high-duration protocol, it was important to check if there were differences in Lyapunov values between trials of both hands and group.

Table 3.
Characterization of Variables: Lyapunov values for the mediolateral, anteroposterior, and vertical axis between trials for each hand and group.

Group/Trial			Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6		Test Statistics	
			M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	H	Sig.
Fibromyalgia Group	Preferred	LyE ML	22,6	7,3	21,4	11,7	23,6	11,0	20,7	12,5	18,0	8,4	21,8	11,8	2,36	0,80
		LyE AP	18,3	5,6	21,3	6,1	23,2	7,3	19,5	8,7	18,4	8,9	22,6	4,8	5,99	0,31
		LyE V	18,8	7,8	18,9	6,6	21,5	7,4	18,4	6,9	19,8	5,0	22,3	8,3	2,41	0,79
	Non-Preferred	LyE ML	22,8	12,1	21,6	8,2	15,7	7,1	22,6	9,9	20,8	9,0	21,7	12,5	4,34	0,50
		LyE AP	21,3	5,2	21,7	5,1	17,3	4,8	18,4	5,2	26,6	11,6	18,4	3,7	7,96	0,16
		LyE V	20,4	6,3	18,1	4,2	18,9	4,9	25,0	9,6	24,8	8,3	23,0	6,7	6,81	0,24
Control Group	Preferred	LyE ML	18,3	6,4	24,1	9,5	21,7	9,9	20,3	13,2	25,1	6,6	18,7	5,6	6,80	0,24
		LyE AP	19,3	7,5	16,1	7,1	19,6	8,2	16,0	7,6	16,6	6,4	20,8	10,8	3,33	8,22
		LyE V	16,7	4,5	16,2	3,9	19,2	8,2	23,7	8,2	20,9	6,9	21,7	5,1	0,65	0,15
	Non-Preferred	LyE ML	18,8	9,8	21,9	13,5	23,1	8,4	17,9	10,4	18,1	6,9	21,6	6,4	5,34	0,38
		LyE AP	16,6	6,6	21,9	6,6	21,7	11,5	15,8	5,3	17,7	8,6	16,5	6,9	5,51	0,36
		LyE V	23,6	10,8	18,8	6,6	18,7	5,1	20,2	7,9	22,7	9,4	21,5	8,4	1,97	0,85

LyE ML – Lyapunov mediolateral; LyE AP – Lyapunov anteroposterior; LyE Vert – Lyapunov Vertical; M – Mean; SD – standard deviation; H – Kruskal-Wallis; Sig. – significance Level

There were no significant differences between trials for both hands in fibromyalgia and control groups, which means that the FTT protocol was rigorous and well performed. In Table 4 and Table 5, the values for statistical analysis and significance level for the variables of Lyapunov mediolateral, anteroposterior and vertical values, are presented between hands, per group and, between groups.

Table 4.
Characterization of Variables for statistical tests and significant values: Lyapunov for the mediolateral, anteroposterior, and vertical axis, between hands and per group.

Group/Hand		Preferred		Non-Preferred		Test Statistics	
		Mean	SD	Mean	SD	U	Sig.
Fibromyalgia	LyE ML	21.329	10.282	20.854	9.810	1721.000	0.916
	LyE AP	20.528	7.072	20.646	6.967	1715.000	0.891
	LyE V	19.905	6.908	21.694	7.172	1471.000	0.147
Control	LyE ML	21.360	8.945	20.244	9.354	1630.000	0.372
	LyE AP	18.084	7.922	18.372	7.906	1748.000	0.785
	LyE V	19.751	6.671	20.926	8.106	1745.000	0.773

LyE ML – Lyapunov mediolateral; LyE AP –Whitney; Sig. – significance
Lyapunov anteroposterior; LyE Vert – LyapunovLevel
Vertical; SD – standard deviation; U – Mann

There were no significant differences between hands in both groups, Fibromyalgia, and controls.

Table 5.
Characterization of Variables for statistical tests and significant values: Lyapunov for the mediolateral, anteroposterior, and vertical axis, between groups. In bold are the variables with significant differences.

LyE/Group	Fibromyalgia		Control		Test Statistics		
	Mean	SD	Mean	SD	U	Sig.	Effect Size
LyE ML	21.092	10.009	20.802	9.130	7052.000	0.958	
LyE AP	20.587	6.990	18.228	7.882	5448.000	0.002	0.972
LyE V	20.799	7.068	20.339	7.415	6669.000	0.439	

LyE ML – Lyapunov mediolateral; LyE AP – Lyapunov anteroposterior; LyE Vert – Lyapunov Vertical; SD – standard deviation; U – Mann Whitney; Sig. – significance Level

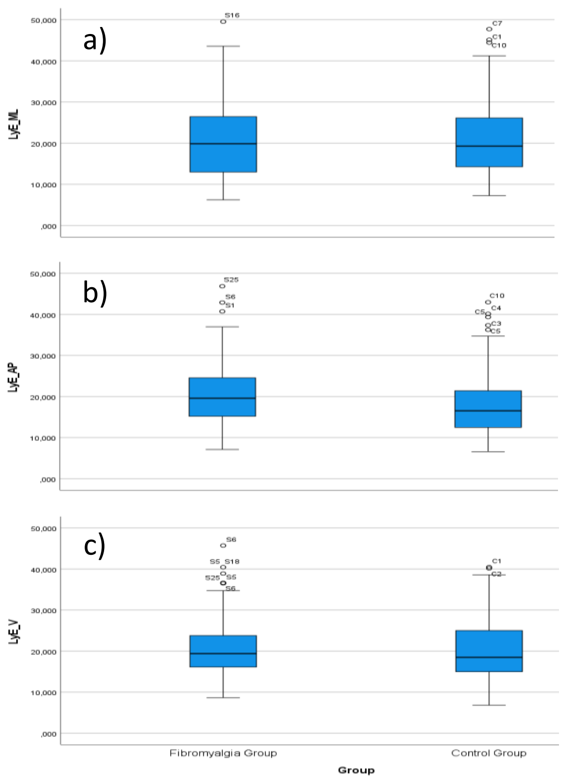

Figure 8. Statistical Descriptive Analysis for FTT Between Groups. Boxplots: a) represents the Lyapunov of Mediolateral accelerations, b) represents the Lyapunov of Anteroposterior accelerations, and c) represents the Lyapunov of Vertical accelerations. Nota: La figura 8 ha sido sustituida, ya que las letras a, b y c estaban cortadas y desplazadas en el documento.

Although Lyapunov values for FTT in all movement axis were higher in fibromyalgia patients, there were no significant differences in the mediolateral and vertical movements, but for the anteroposterior movements, there were significant differences (U=5448.000; p=0.002). The effect size was calculated for the variables with considerable differences, showing a large effect (Fields, 2018).

For a better understanding of the results, the boxplots for descriptive statistical analysis are presented.

The a, b, and c boxplots represent the Lyapunov values for the mediolateral, anteroposterior, and vertical axis, respectively.

The results showed a higher data dispersion in the fibromyalgia group, which means that Fibromyalgia has higher variability in the finger tapping test when compared to controls.

Discussion

This retrospective cross-sectional study intended to verify if the variability, through the Lyapunov measure, in gross and fine motor movements is higher in patients with Fibromyalgia when compared to the control group. According to the results presented in this study, fibromyalgia patients show a more incoherent or irregular pattern of the linear acceleration peaks than the controls, representing a greater irregularity in walking and sitting, and standing tasks than the control group. Regarding variability, the mean Lyapunov values in FM patients are higher in gait tasks for the anteroposterior and mediolateral movements, but the same does not occur for vertical movements. Although there are no significant differences, the fact that the values were higher in mean shows a propensity for higher instability and variability in the fibromyalgia group in these axes of movement. Lyapunov values in patients with Fibromyalgia present significantly higher variability in the anteroposterior movements when performing the sit and stand task.

In contrast to the values for the mediolateral and vertical axes, which were lower compared to the controls. These values should be considered in future studies and with other analysis methods, such as recurrence analysis. Probably they might show more detailed and important information to characterize FM patients through gait variability analysis.

The results in this study also showed higher variability in the fibromyalgia group for the finger tapping test than in controls, which reinforces the thesis that fibromyalgia patients have more difficulty controlling fine motor movements. The greater variability found also shows the scope that FM has, which is partly explained by the multifactorial symptoms present in it. Hypothetical models previously published (Pinto et al., 2023; Yunus, 2008) show that these results can be explained by neural dysregulation, suggesting a direct link between the neurophysiological mechanisms of pain and the motor manifestations of fibromyalgia.

Conclusions

Therefore, in conclusion, patients with Fibromyalgia showed more difficulty in controlling the anteroposterior movements during the up and down sequence in the sit and stand test. This could be justified by the pain and fatigue that FM patients felt and referred during the execution of the test. On the other hand, controls were more consistent in the execution of the task, as they managed to better control the anteroposterior oscillations. Participants in the control group can also perform the finger tapping test with greater control. These results may allow a better understanding and characterization of both Fibromyalgia and control groups.

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