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ANALYSIS OF THE COMPLEXITY AND VARIABILITY OF FINE AND GROSS MOTOR TASKS IN FIBROMYALGIA PATIENTS: PRECISION AND RETROSPECTIVE CROSS-SECTIONAL STUDIES

Dissertação

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Analysis of the complexity and variability of fine and gross motor tasks in fibromyalgia patients: precision and retrospective cross-sectional studies

Abstract

Fibromyalgia (FM) can be defined as a non-inflammatory chronic and widespread pain disease (Gentile et al., 2019) that present and series of other symptoms such as fatigue, Allodynia, Hyperalgesia, functional impairment, balance deficit, and others (ACSM, 2021; Rasouli et al., 2017). FM is considered to be a disease or syndrome that shows a central nervous system dysfunction in pain modulation (Gentile et al., 2019). This functional impairment in FM patients may be related to disturbances in motor functions, such as deficits in fine and gross motor control (Pérez-de-Heredia-Torres et al., 2013; Rasouli et al., 2017). Until today, it is still impossible to confirm the diagnosis of Fibromyalgia because no clinical tests are available for this purpose (ACSM, 2021).

The present dissertation intends to verify if Inertial Measurement Units (IMU) are instruments that can facilitate the applicability (Study 1) of FTT; Analyze and interpret entropy values during fine and gross motor control tasks (Study 2), and assess the variability during the same fine and gross motor control tasks (Study 3) of individuals with FM diagnosis; and also to verify if the IMU with the non-linear analysis can characterize FM patients.

The sample of 20 female subjects, 10 with FM and 10 without, with ages between 20 and 70 years old, was divided into experimental and control groups. Participants were asked to perform de finger tapping test with both hands, the gait task, and the sit and stand test. IMUs were used in all tasks to collect the required data for each study. Non-linear measures of entropy and variability were used to allow a detailed and deeper motor control analysis, focusing on the process and on the quality of movement (Azami et al., 2017).

The results showed that using inertial sensors may be of great applicability in the finger tapping test, and it could be a possible alternative to the traditional method. This method allows the tridimensional collection and analysis of other important information that we can only access by looking at the process and not just the results in a more practical, faster, and cheaper way. And the use of IMU, along with non-linear analysis in fine and gross motor control, could allow a better understanding and characterization of both groups, Fibromyalgia, and control, through the analysis of entropy and variability.

In conclusion, the use of inertial sensors to collect data from fine and gross motor has great potential and brings innovation to exercise researchers and professionals.

Keywords: Fibromyalgia; Fine Motor Control; Gross Motor Control; FTT; Gait; Sit and Stand; Entropy; Lyapunov; IMU

Análise da complexidade e da variabilidade de tarefas motoras finas e grossas em pacientes com fibromialgia: estudo de precisão e transversais retrospetivos

Resumo

A fibromialgia (FM) pode ser definida como uma doença não inflamatória com dor crónica generalizada (Gentile et al., 2019), e que apresenta uma série de outros sintomas como a fadiga, alodinia, hiperalgesia, comprometimento funcional, deficits de equilíbrio, entre outros (ACSM, 2021; Rasouli et al., 2017). A FM é considerada uma doença ou síndrome que apresenta uma disfunção por parte do sistema nervoso central no processamento e regulação da dor (Gentile et al., 2019). Esse comprometimento funcional em pacientes com FM pode estar relacionado com a presença de distúrbios motores, como deficits na motricidade fina e grossa (Pérez-de-Heredia-Torres et al., 2013; Rasouli et al., 2017). Até hoje ainda não é possível confirmar o diagnóstico de fibromialgia, pois não existem testes clínicos disponíveis para o efeito (ACSM, 2021).

A presente dissertação pretende verificar se os sensores inerciais (IMUs) são instrumentos que podem facilitar a aplicação (Estudo 1) do FTT; analisar e interpretar valores de entropia durante a realização de tarefas de motricidade fina e grossa (Estudo 2) e, analisar a variabilidade durante a execução das mesmas tarefas de controlo motor fino e grosso de indivíduos com FM, e verificar se o IMU juntamente com a análise não-linear, permite uma caracterização da fibromialgia.

A amostra desta dissertação é constituída por 20 sujeitos do sexo feminino, 10 com FM e 10 sem FM, com idades compreendidas entre os 20 e os 70 anos, divididos em dois grupos, grupo experimental e grupo de controlo, respetivamente. Foi solicitado aos participantes que realizassem três tarefas motoras: o finger tapping test em ambas as mãos, a marcha e o teste de sentar-e-levantar. Os IMUs foram utilizados em todas as tarefas para recolher os dados necessários para cada estudo, de modo a serem aplicadas medidas de análise não-linear de entropia e variabilidade. Este tratamento de dados foi utilizado para permitir uma análise mais detalhada e profunda do controlo do movimento, com principal foco no processo e na qualidade do movimento (Azami et al., 2017).

Os resultados desta dissertação mostraram que a utilização de sensores inerciais parece ter uma grande aplicabilidade no teste de finger tapping, e que o mesmo pode ser uma possível alternativa ao método validado. O IMU permite uma recolha e análise

tridimensional, o qual possibilita entender o processo de controlo do movimento e não apenas o resultado, fazendo-o de forma mais prática, rápida e económica. O uso de IMUs juntamente com análises não-lineares na motricidade fina e grossa pode permitir uma melhor compreensão e caracterização de ambos os grupos, fibromialgia e controlo, através da análise da entropia e da variabilidade.

Em conclusão, o uso de sensores inerciais apresenta um grande potencial e traz inovação para investigadores e profissionais do exercício.

***Palavras-Chave**: Fibromialgia; Motricidade Fina; Motricidade Grossa; FTT; Marcha; Sentar e Levantar; Entropia; Lyapunov; IMU*

General Index

List of Abbreviations

FM – Fibromyalgia;

FIQ – Fibromyalgia Impact Questionnaire;

FTT – Finger Tapping Test;

IMU – Inertial Sensor;

2D – Bidimensional;

3D – Tridimensional;

s – Seconds;

ms – milliseconds;

IQR – Inter-Quartile Range

AD – Alzheimer Disease;

PD – Parkinson's Disease;

EEG – Electroencephalography;

fNIRS – Functional Near-Infrared Spectroscopy;

ACR – American College of Rheumatology;

VAS – Visual Analog Scale;

SD – Standard Deviation;

Hz – Hertz;

RCME – Refined-Composite Multiscale Entropy;

Nbeats – Number of Touches in the Surface;

Tbeats – Time Between Touches in the Surface;

Ent ML – Incremental Entropy for Mediolateral Axis;

Ent AP - Incremental Entropy for Anteroposterior Axis;

Ent V - Incremental Entropy for Vertical Axis;

H – Kruskal-Wallis;

U – U-Mann Whitney;

Sig. – Significance Level;

Z – Statistical Z Test.

t – t Test

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CHAPTER I

INTRODUCTION AND CONCEPTUAL FRAMEWORK

1. INTRODUCTION

The present dissertation is organized into five chapters. Chapter I describes the dissertation's introduction to the theme, a conceptual framework, a presentation of the theoretical model, and the general hypothesis and aims. Chapter II consists of a study that verifies the levels of agreement between two measurement methods of FTT, the traditional method and the IMU method, through the Bland-Altman technique. Chapter III verifies entropy values in the Fine and Gross Motor Control for fibromyalgia patients e controls. Chapter IV verifies the values of variability in fine and Gross Motor Control for Fibromyalgia patients and controls. And finally, chapter V presented the general conclusions and recommendations. The appendixes are at the end of this document.

2. CONCEPTUAL FRAMEWORK

2.1.Fibromyalgia

Fibromyalgia (FM) is a disabling disease with chronic and widespread muscle pain associated with fatigue, sleep disorders, cognitive impairment, and a number of other physical and psychopathological symptoms (Gentile et al., 2019), such as hypersensitivity, multiple and diffuse sensitive points (Tender Points), morning stiffness, memory impairment, headaches, paresthesia[1], anxiety and depression, cognitive dysfunction, fine motor weakness, environmental sensitivity to cold, lights, noise, and odor, headaches, and balance deficit. The main symptoms of this disease may get worse with increased emotional stress, inadequate sleep, injury or surgery, physical inactivity, or excessive physical activity (ACSM, 2021). FM symptoms don't have a specific pattern, and they can intensify, diminish and move to different parts of the body at different moments of the day.

In the early ages, Fibromyalgia was described as a rheumatic disease or muscular rheumatism. FM was initially defined as "a special pain, usually driven by an inflammatory action, involving fibrous and white tissues, belonging to muscles and joints, like tendons, aponeurosis" (Wang et al., 2015).

Despite the symptoms of soft tissue pain, there is no evidence that tissue inflammation exists in patients with Fibromyalgia (Bhargava & Hurley, 2022). Although some authors

[1] Paresthesia is the sensation of burning, prickling, tingling, or itching of skin with no apparent cause.

refer that fibromyalgia patients are unable to process pain in the brain (Bhargava & Hurley, 2022), others show that there is a central flaw in pain modulation with an abnormal response to nociceptive stimulation (Gentile et al., 2019). So, Fibromyalgia is presently considered as a syndrome that presents a hypersensitivity to stimuli that are not normally painful (central sensitization syndrome) (Bhargava & Hurley, 2022). Central sensitization is commonly seen in various disorders or chronic diseases such as Fibromyalgia, and it can be defined as the increased responsiveness of the central nervous system to different and nonpainful stimuli. This excessive sensitivity in the body due to central sensitization results in allodynia[2] and hyperalgesia[3] And eventually leads to chronic and generalized pain (Cagnie et al., 2014; A. Eken et al., 2018; Nijs et al., 2012). Some authors reveal that both the increase in brain activity and the changes observed in the Gray matter region of the brain, which tend to result in decreased pain modulation in individuals with Fibromyalgia, may be related to central sensitization. (A. Eken et al., 2018). In addition to pain and sensorial symptoms, activity limitation and functional impairment are also common in these individuals. This functional impairment may be related to the presence of disturbances in motor functions, such as deficits in fine motor control and gross motor control (Pérez-de-Heredia-Torres et al., 2013; Rasouli et al., 2017).

2.1.1. Etiology and Diagnostic

Fibromyalgia affects approximately 2-4% of the world's population, and women are more frequently affected (ACR, 2022). FM is a complex pathology with an unknown etiology and unclear pathophysiological mechanisms (Gentile et al., 2019). According to some authors and the American college of rheumatology, Fibromyalgia might be associated with some triggering factors, such as infectious diseases, psychiatric or neurological disorders, spine problems, diabetes, injuries, rheumatic pathologies, and even physical or emotional stress (ACR., 2022; Maffei, 2020). There seems to be certainty that Fibromyalgia is not an inflammatory, joint, muscular, or autoimmune disease. But it is somehow associated with genetic factors, and people with relatives who have FM are more likely to have this disease (ACR., 2022; ACSM, 2021).

[2] Allodynia is a pain in response to normally nonpainful stimuli.
[3] Hyperalgesia is an increased pain in response to normally painful stimuli.

Until today, it is still impossible to confirm the diagnosis of Fibromyalgia because no clinical tests are available for this purpose (ACSM, 2021). The clinical diagnosis of Fibromyalgia must be carried out by specialized physicians and is based on the administration of the Widespread Pain Index (WPI), which consists of the specification of the number of points or areas in which the patient has had pain over the past week. Along with the WPI, the presence of somatic symptoms such as fatigue, cognitive impairment, and non-restorative sleep should also be evaluated and accounted for. For this purpose, the Symptom Severity Scale (SSS) and Extent of Somatic Symptoms (ESS) are used, allowing the quantification of the severity of these symptoms on a scale from 0 to 12 and 0 to 3, respectively, where 0 represents 'no problems' or 'no symptoms,' and 12 or 3 represents 'severe symptoms.' So, the criteria for the clinical diagnosis of Fibromyalgia are a score greater than 7 out of 19 tender points, a score of 5 out of 12 on the SSS scale, the presence of generalized pain in 4 out of 5 body regions for at least three months at a similar level and the absence of other diseases or disorders that may justify it the pain (ACR., 2022; ACSM, 2021; Maffei, 2020).

In parallel to the diagnosis, the Fibromyalgia Impact Questionnaire (FIQ), a self-administered questionnaire, has also been used to assess and monitor the current state of health of FM patients in a research or clinical environment (ACR., 2022).

3. THEORETICAL MODEL

3.1.Dynamical Systems

The theoretical model supporting this dissertation's development is the theory of dynamical systems in the area of motor behavior (Kelso, 1995). Dynamical systems theory is a multidisciplinary systems-driven approach that embraces mathematics, physics, biology, psychology, and chemistry, to describe systems that constantly change and evolve over different timescales (Davids et al., 2003). So, dynamical systems in human movement are represented by an interaction between subsystems that depend on each other, for example, the nervous, proprioceptive, and musculoskeletal systems and others (Davids et al., 2003). Dynamic systems also state that the motor patterns of human systems emerge from self-organization processes between both biological and physical systems (Davids et al., 2003; Goldfield, 1995; Kelso, 1995), in which self-organization is one of the five propositions suggested by Goldfield (1995) to analyze action systems. This proposition describes the processes of how the motor system, with all its degrees of freedom, behaves in a non-linear way and how it produces adaptable spatiotemporal patterns. In this sense, changes in biological systems, such as Fibromyalgia, can originate in specific patterns of behavior observed during movement or movement coordination analysis. According to Bernstein (1967) and Turvey (1990), motor coordination is the movement pattern that results from the simultaneous action of several muscle contractions (degrees of freedom) to produce a specific output (Bernstein, 1967; Turvey, 1990).

While this output may be very accurate, the process that takes place can have higher variability (Bernstein, 1967). This natural movement variability provides a constant adaptation for the same action as if the motor system were looking for something permanently stable (Catela, 2015). That is why in the last few decades, one of the preferred methods for analyzing a dynamical system has been the non-linear analysis, and also because this method can be described by mathematical equations that highlight the properties of the system adaptations through time (i.e. recurrence quantification analysis, entropy analysis (Azami et al., 2017; Yentes & Raffalt, 2021) or Lyapunov exponent (Mehdizadeh, 2018).

4. PROBLEM PRESENTATION AND GOALS

FTT, as a validated task, is one-dimensional, which counts only the number of touches on the surface. Nonetheless, we question whether the movement that the finger makes by itself might not bring us other types of information that would lead us to understand the performer's motor control process and not just the result. One of the ways to do this is to use the quantitative analysis of the movement that is usually used in the kinematic analysis in biomechanics, but this data treatment is either financially or time-consuming. In recent years, IMUs have been developed as a form of quantitative evaluation of movement, and this instrument, due to its size and cost, has brought new opportunities for application in different types of tasks (Camomilla et al., 2018). In this sense, we question if we are able to apply this instrument? Is it possible to collect data simply and quickly?

The unknown etiology of Fibromyalgia has led to different studies to understand the processes that trigger the signs and symptoms of this disease, now reaching a possible alteration in the central nervous system. In this line of thought, another experimental question is whether changes in motor processing of fibromyalgia patients are verified in more demanding tasks like happen to neurodegenerative diseases of the central nervous system?

4.1. Objectives

Considering the importance of performing a detailed analysis of the index finger movement, the first objective of this dissertation is to verify if Inertial Measurement Unit (IMU) or Inertial Sensors are instruments that can simplify the applicability (Study 1). The second objective is to analyze and interpret the values of entropy during fine and gross motor control tasks (Study 2), and, the third objective is to assess the variability during the same motor control tasks (Study 3) of individuals with a fibromyalgia diagnosis.

REFERENCES

ACR., A. C. o. R. (2022). *American College of Rheumatology*. American College of Rheumatology. Retrieved 17 dec 2022 from https://www.rheumatology.org/

ACSM. (2021). *American College of Sports Medicine - Guidelines for Exercise testing and Prescription* (Eleventh Edition ed.). Copyright.

Azami, H., Rostaghi, M., Abasolo, D., & Escudero, J. (2017). Refined Composite Multiscale Dispersion Entropy and its Application to Biomedical Signals. *IEEE Transactions on Biomedical Engineering*, *64*(12), 2872-2879. https://doi.org/10.1109/tbme.2017.2679136

Bernstein, N. (1967). *The co-ordination and regulation of movements*. Pergamon Press.

Bhargava, J., & Hurley, J. A. (2022). Fibromyalgia. In *StatPearls*. StatPearls Publishing

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Cagnie, B., Coppieters, I., Denecker, S., Six, J., Danneels, L., & Meeus, M. (2014). Central sensitization in fibromyalgia? A systematic review on structural and functional brain MRI. *Semin Arthritis Rheum*, *44*(1), 68-75. https://doi.org/10.1016/j.semarthrit.2014.01.001

Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. *Sensors*, *18*(3), 873. https://doi.org/10.3390/s18030873

Catela, D., Branco, M., Seabra, A., Mercê, C. (2015). *Comportamento Motor: Constrangimentos & Affordances*.

Davids, K., Glazier, P., Ara??Jo, D., & Bartlett, R. (2003). Movement Systems as Dynamical Systems. *Sports Medicine*, *33*(4), 245-260. https://doi.org/10.2165/00007256-200333040-00001

Eken, A., Gökçay, D., Yılmaz, C., Baskak, B., Baltacı, A., & Kara, M. (2018). Association of Fine Motor Loss and Allodynia in Fibromyalgia: An fNIRS Study. *J Mot Behav*, *50*(6), 664-676. https://doi.org/10.1080/00222895.2017.1400947

Gentile, E., Ricci, K., Delussi, M., Brighina, F., & de Tommaso, M. (2019). Motor Cortex Function in Fibromyalgia: A Study by Functional Near-Infrared Spectroscopy.

Pain Research and Treatment, *2019*, Article 2623161. https://doi.org/10.1155/2019/2623161

Goldfield, E. (1995). *Emergent Forms - Origins and Early Development of Human Action and Perception*. Oxford University Press, Inc.

Kelso. (1995). *Dynamic Patterns*. MITT.

Maffei, M. E. (2020). Fibromyalgia: Recent Advances in Diagnosis, Classification, Pharmacotherapy and Alternative Remedies. *International Journal of Molecular Sciences*, *21*(21), 7877. https://doi.org/10.3390/ijms21217877

Mehdizadeh, S. (2018). The largest Lyapunov exponent of gait in young and elderly individuals: A systematic review. *Gait Posture*, *60*, 241-250. https://doi.org/10.1016/j.gaitpost.2017.12.016

Nijs, J., Meeus, M., Van Oosterwijck, J., Ickmans, K., Moorkens, G., Hans, G., & De Clerck, L. S. (2012). In the mind or in the brain? Scientific evidence for central sensitisation in chronic fatigue syndrome. *European Journal of Clinical Investigation*, *42*(2), 203-212. https://doi.org/10.1111/j.1365-2362.2011.02575.x

Pérez-de-Heredia-Torres, M., Martínez-Piédrola, R. M., Cigarán-Méndez, M., Ortega-Santiago, R., & Fernández-de-Las-Peñas, C. (2013). Bilateral deficits in fine motor control ability and manual dexterity in women with fibromyalgia syndrome. *Exp Brain Res*, *226*(1), 137-143. https://doi.org/10.1007/s00221-013-3417-4

Rasouli, O., Fors, E. A., Borchgrevink, P. C., Öhberg, F., & Stensdotter, A. K. (2017). Gross and fine motor function in fibromyalgia and chronic fatigue syndrome. *J Pain Res*, *10*, 303-309. https://doi.org/10.2147/jpr.S127038

Turvey, M. T. (1990). Coordination. *American Psychologist*, *45*(8), 938-953.

Wang, S. M., Han, C., Lee, S. J., Patkar, A. A., Masand, P. S., & Pae, C. U. (2015). Fibromyalgia diagnosis: a review of the past, present and future. *Expert Rev Neurother*, *15*(6), 667-679. https://doi.org/10.1586/14737175.2015.1046841

Yentes, J. M., & Raffalt, P. C. (2021). Entropy Analysis in Gait Research: Methodological Considerations and Recommendations. *Ann Biomed Eng*, *49*(3), 979-990. https://doi.org/10.1007/s10439-020-02616-8

CHAPTER II

PRECISION OF AN INERTIAL SYSTEM TO EVALUATE THE FINGER TAPPING TEST

Abstract

In a clinical context, researchers often have the need to evolve in measurement methods (Kalra, 2017). The Finger Tapping Test (FTT) is a measuring tool that evaluates fine motor control and is usually used to assess neurodegenerative diseases (Roalf et al., 2018; Suzumura et al., 2016). Although this test consists of a result analysis based on counting the number of touches on the surface (Reitan & Wolfson, 1985), other FTT variables can be investigated. By investigating the process of execution, it would be possible to analyze motor control and behavior more deeply. However, it is necessary to develop a more sensitive method for these variables. Inertial sensors can accurately collect acceleration and angular velocity in the three-movement planes (Camomilla et al., 2018). The use of this instrument during the application of the FTT test can therefore consist of a new evaluation method. But every time there is the need to replace one method with another, it is necessary to evaluate the differences between both (Giavarina, 2015). Bland-Altman introduced a method that illustrates the agreement between two quantitative measurements (Doğan, 2018; Kalra, 2017). So, the aim of this study is to verify the levels of agreement in the performance of the Finger Tapping Test using IMUs, through the Bland-Altman technique. This study's sample was composed of 238 FTT trials collected from 20 women (46.150 ± 12.835 years old). The results showed a high agreement between both methods, which might indicate that inertial sensors can be used as a measurement method for FTT test.

Keywords: IMU; FTT; Bland-Altman; Agreement

1. INTRODUCTION

In a medical, clinical, or practical context, researchers often have the need to develop new measurement methods. This need to evolve and replace an old method with an upgrade version or even a completely new one, allowing researchers to collect as much data as possible and with good or even better quality, has become indispensable in the research area (Kalra, 2017). A comparison between two methods of measurement to determine whether a new method can be safely used as an alternative to a traditional one is the main goal that led us to write this article.

In the late eighties and early nineties, Reitan and Wolfson (1985) developed the Healstead-Reitan Neuropsychological Test Batteries. These test batteries were used to characterize the overall impairment degree of neuropsychological functioning (Incagnoli, 1997). One of those tests is The Finger Tapping Test (FTT), which is a measuring tool that evaluates fine motor control and is usually used to assess neurodegenerative diseases such as Dementia, Alzheimer's, and Parkinson's Disease (Roalf et al., 2018; Suzumura et al., 2016). In this test, patients have to touch a surface with their finger as quickly as possible for 10 seconds, 5 to 10 trials for each hand (Reitan & Wolfson, 1985). This test's primary approach consists of a product measure based on counting the number of touches on the surface (Reitan & Wolfson, 1985).

Nonetheless, other FTT variables can be investigated, such as range of motion or finger amplitude, execution speed, the time between touches, and even the interaction between them. By investigating this process analysis, it would be possible to analyze motor control and behavior more profoundly and possibly detect different movement patterns in clinical populations. However, for that purpose, it is necessary to develop a method that is more focused on the process and more sensitive to these variables.

The inertial measurements units (IMU), also known as inertial sensors, consist in small portable biomechanical devices which can collect acceleration, angular velocity, and earth magnetism in the three planes of motion with higher frequency and accuracy (Camomilla et al., 2018). The use of this instrument during the application of the FTT can therefore consist of a new evaluation method, more practical, easier, and even more accurate. Furthermore, this IMU application can maintain the analysis of the results relative to the number of touches on the surface and additionally afford the analysis of the execution process.

Every time we need to replace one measurement method with another, we must apply some tools to evaluate their differences (Giavarina, 2015). During the new method's evaluation and replacement, it is necessary to ensure an agreement between the new and existing measurement methods (Kalra, 2017). In this sense, the Correlation Coefficient can be a viable option to verify how strongly related two variables are (Giavarina, 2015). However, a high correlation does not mean that there is good agreement between the two measurement methods. The correlation can be misleading and inappropriate because it does not measure the agreement between two methods or variables, whatever the strength of a relation between them (Giavarina, 2015).

The concern with the incorrect use of correlation coefficients to compare a new method with an existing one led Bland and Altman (1986) to develop a new technique that ended up being designated as the Bland-Altman technique (Doğan, 2018). The authors introduced a graphical method that illustrates the agreement between two quantitative measurements by studying the mean difference and calculating the limits of agreement or confidence limits (Doğan, 2018; Kalra, 2017). Since its development, this technique has been applied by different authors and in several contexts, being considered "the most appropriate way to determine the limits of agreement between measurements" (Doğan, 2018).

Considering the constant need to develop new measurement methods that allow collecting more data with higher quality (Kalra, 2017), as well as the emergence of new portable devices with great collection capacity, such as IMUs (Camomilla et al., 2018). The present study aims to verify the levels of agreement in the performance of the Finger Tapping Test using IMUs, through the Bland-Altman technique. The validation of this new measurement method will allow the analysis of not only the results but also the process of execution, which may be important for a deeper understanding of the motor control of individuals with neurodegenerative diseases.

2. METHODS

2.1. Sample

The sample for this study was composed of 238 FTT trials collected from 20 selected women (Table 1), for convenience (participants who were willing to participate in the study), with ages between 20 and 70 years old, with and without a fibromyalgia diagnostic (10 in each group).

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

Since the present study aimed to verify the level of agreement of a new evaluation method for the FTT, which is based on a specific statistical treatment to evaluate the differences between methods in the same collection, i.e., the same subject, the inclusion of a special population, i.e., Fibromyalgia, in the collections will not affect this evaluation. However, in the future, if the new method proves to be reliable, the differences between subjects with and without Fibromyalgia can be explored.

The project has been approved by the Ethics Committee of the Polytechnic Institute of Santarém (Nº 2A-2022 ESDRM). All participants signed an informed consent to participate in the study and were recruited through social platforms.

2.2. Procedures

Participants were asked to perform six trials of the FTT at their maximum speed for ten seconds per trial, starting with the preferred hand and repeating the entire process with the other hand. The performance of 6 trials per hand was defined according to the previous literature, which has used 5 to 10 trials per hand, scoring the test by the average number of touches on the surface of the best five trials (Christianson, 2004; Reitan & Wolfson, 1985). A high-speed camera (Casio Exilim EX-ZR200) with a sample rate of 240Hz was used to collect data during FTT. An inertial sensor was used to collect linear acceleration and angular velocity.

The camera was at a distance that caught the hand and fingers of participants. A rubber finger with a black dot was placed on the index finger to allow automatic digitization of the finger position in Kinovea software (Figure 1) (Charmant, 2021). To calibrate the virtual space in the software, it was also used calibration volume (Figure 2). The inertial sensor was also placed on the index finger attached to the rubber finger (Figure 1 and Figure 3), to allow the collection of tridimensional linear acceleration and angular velocity at the same time. YAT software (Klay, 2021) was used to record the inertial sensor data.

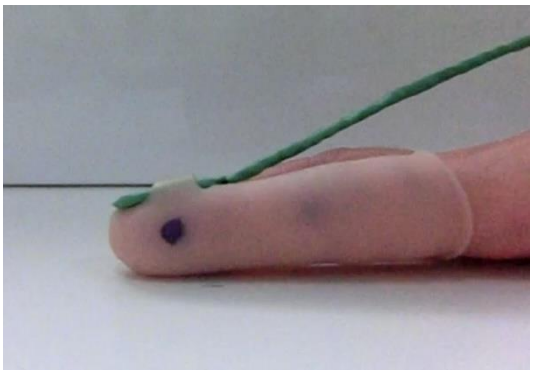

Figure 1. FTT Index Finger

Figure 2. Kinovea Calibration Volume

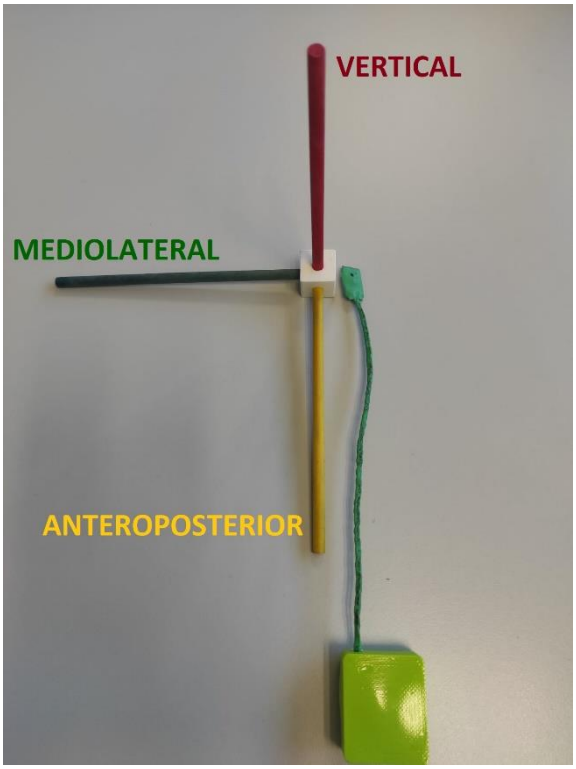

Figure 3. Inertial Sensor 3D axis

After digitizing the videos in the Kinovea Software, the index position variable was extracted and imported to MATLAB (MATLAB, 2021), as well as the inertial sensor's raw data. After importing the data, they were analyzed by a custom MATLAB routine, which allowed the synchronization of position data (retrieved from Kinovea) with the vertical linear acceleration data (retrieved from IMU), as well as the identification of touches in both methods.

Synchronization (Figure 4) was performed by selecting the 1st touch on the surface in the finger's vertical position graph (kinovea data) and selecting the 1st acceleration peak

in the finger's vertical or linear acceleration graph (IMU data). From the 1st touch of the finger on the surface, 10 seconds of task execution were counted.

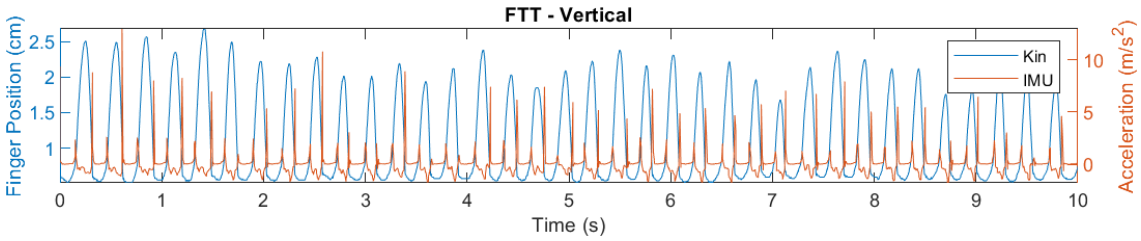

Figure 4. Example of time series synchronization of Kinovea and IMU data

The detection of touches was performed using the “findpeaks” function of MATLAB, with the definitions of “MinPeakDistance” of 0.120s and 'MinPeakProminence' of 20% of the acceleration amplitude, meaning that the detection of peaks does not occur below 120ms, nor at peaks less than 20% of the acceleration amplitude. Lower amplitude values caught many subpeaks that were part of the pattern but were not touches on the surface. After the detection of the touches, the routine also calculated the time between touches for both methods.

2.3. Statistical Analysis

The measurement methods were compared by using Bland-Altman Plot for the number of touches and for the time between touches. Both variables were calculated by the traditional method, position variables (extracted from the Kinovea Software), and by the new method, linear acceleration (collected by the inertial sensor).

Before the Band-Altman analysis, the normality of the data distribution was verified by the Kolmogorov- Smirnov test, which was not assumed for all variables under analysis. Then, a Bland-Altman non-parametric analysis was used, with confidence limits to be specified by the interquartile range.

The Bland-Altman graph is plotted on the XY axis where the Y-axis represents the difference between the two methods, and the X-axis represents the average of the two measurements. The mean of the two methods is called bias, and the limits of agreement should lie within -1.45 Inter-Quartile Range (IQR) and +1. 45 IQR for a 95% confidence interval (Kalra, 2017; Sedgwick, 2013).

3. RESULTS

The results of the various stages of data treatment are presented below. Figure 5 represents the finger position after Kinovea Software's automatic digitalization and after importing the data into a specific MATLAB routine.

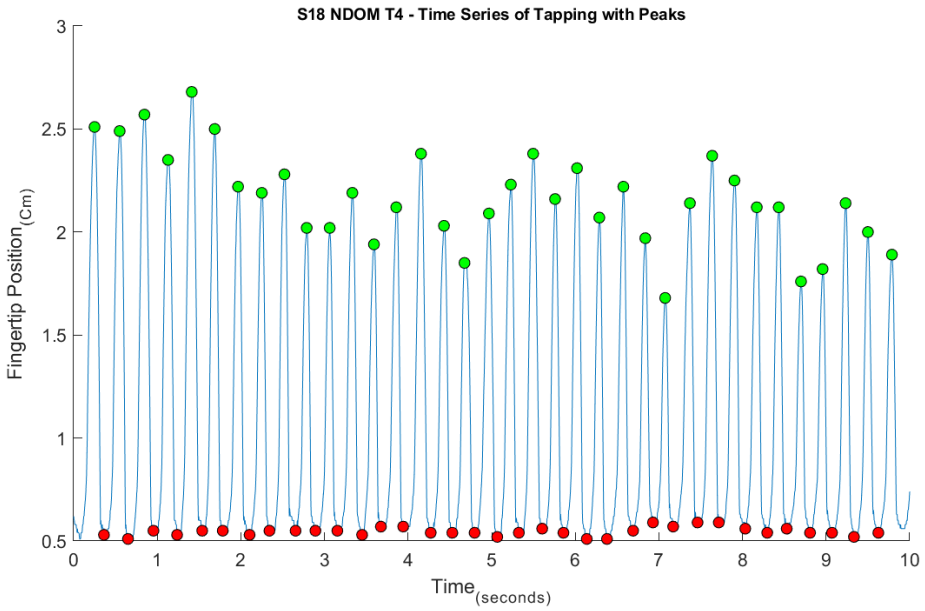

Figure 5. Example of temporal series of FTT Finger Position (red dots – touch on the surface; green dots – maximum vertical position)

Matlab routine was able to detect the finger touches on the surface (red dots) and the maximum vertical position of the finger in each touch (green dots).

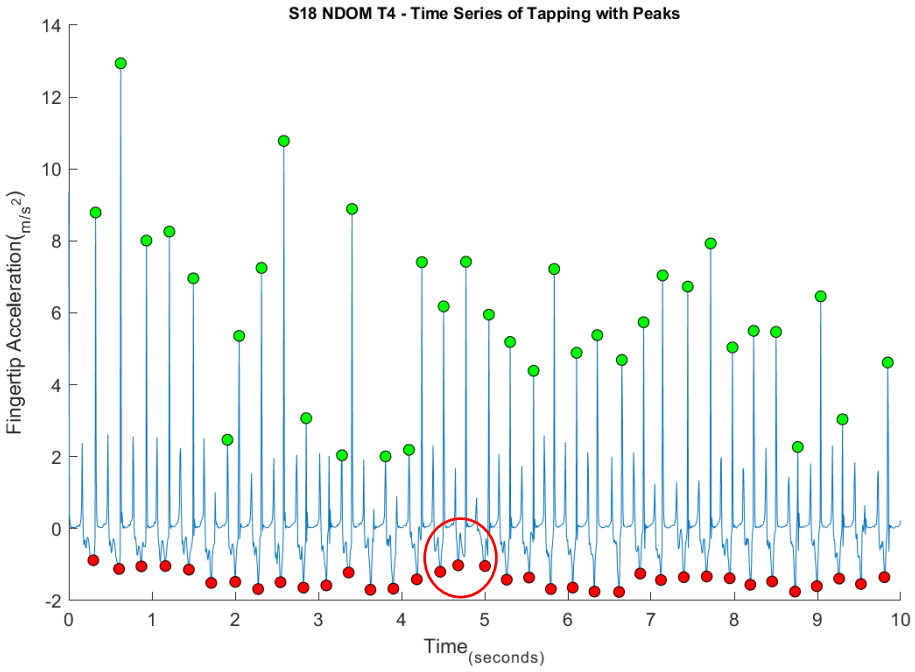

Figure 6. Example of time series of FTT Linear Acceleration, with cases of detection limitations (red circles)

In the finger acceleration plots, data retrieved from IMU, the MATLAB routine had more difficulty finding the same peaks of the pattern. An example of this is the peak represented in the red circle in Figure 6, where it's possible to see that in most of the time series, the peak detected is the second peak of the cycle of touching the surface. However, in this case, the first peak of the cycle was detected.

After data preparation, it was performed the Bland-Altman Plots for the "number of touches" (Figure 7) and "time between touches" (Figure 8).

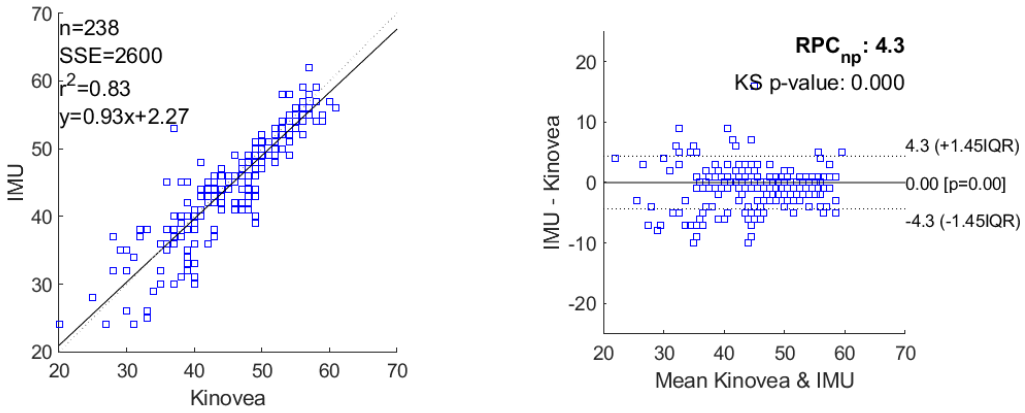

Figure 7. Bland-Altman Plots for Number of Touches for FTT - by Kinovea and IMU

For the number of touches plot (Figure 7), the X-axis represents the average number of touches between Kinovea and Inertial Sensor (IMU) for each FTT trial. In the plot on the right, the Y-axis represents the difference between these two methods. For the present data, the comparison between the number of touches by the two methods, with limits of agreement of 95% (determined by interquartile interval - IQR), revealed a mean difference of 0.00 touches, within an agreement limit or bias between -4.3 and +4.3.

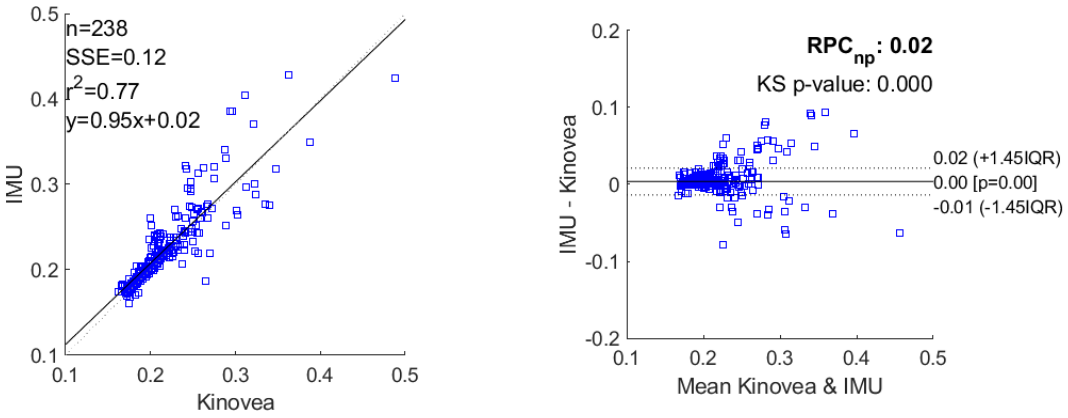

Figure 8. Bland-Altman Plots for Time Between Touches for FTT - by Kinovea and IMU

For the time between touches plot (Figure 8), the X-axis represents the average time between touches in Kinovea and Inertial Sensor (IMU) for each FTT trial, while the Y-axis represents the difference between these two methods. With limits of agreement of 95%, between the two methods, the results revealed a mean difference of 0.00 time between touches, within an agreement limit or bias between -0.01 and +0.02.

4. DISCUSSION

Based on the results of the present study, it was possible to verify that most of the touches in the surface detected by the new method, with acceleration data from IMU, are within the confidence interval. The bias between the number and time between touches was both 0, and the limits of agreement were equivalent to 95% confidence interval. These results support the hypothesis that the use of inertial sensors during the FTT test is a rigorous method to account for the finger tapping number of touches. This new measurement method might be a great substitute for the traditional method of counting to the proposed one, in an opposite way of the video analysis or counting touches on a surface, the inertial sensor allows a 3D analysis of the movement without the need to use three cameras, and the automatic and manual digitalization of the videos for each FTT trials. Furthermore, this inertial sensor will be able to collect more variables, like the interval between touches with a precision of 30ms, which is far below the classically assumed reaction time (Schmidt et al., 2019). It would also be possible to access and analyze the test performance during its execution process and not only analyze the product of number of touches. All these new variables and a new way to look at FTT test will allow a more deep understanding of motor control and behavior during the test, for example by carrying out non-linear analyzes, like multiscale entropy (Azami et al., 2017). In previous studies, Costa et al., (2005) and Costa and Goldberger (2015) were able to observe that in comparison with healthy patients, patients with heart-related diseases had a lower complexity, just by applying and analyzing multiscale entropy to heart rate interbeat intervals (Costa et al., 2005; Costa & Goldberger, 2015). Meaning that there is a possibility to apply multiscale entropy in the interval between touches for FTT, to detect loss of complexity in a variety of neurodegenerative or central nervous system diseases.

This type of information is relevant as it may allow the construction of an FTT analysis software in the future, considering not only the number of touches on the surface but also other process information that has not yet been analyzed. Inertial sensors, in addition to acceleration peaks, also allow the analysis of the acceleration time series, affording us to look at the process of executing the task and not just at the result. It might still be possible, using this new method, to characterize a neurodegenerative and central nervous system disease, through the analysis of more sensitive information, like movement patterns, and not just the number of touches on the surface.

5. CONCLUSIONS

The Inertial Sensor application during the FTT test has a high agreement when compared with the traditional method and might be a more practical and more accessible measurement method to use in a clinical or practical context. This new method is more focused on aspects of information on the process of movement rather than on information on movement product results, which may provide a new way to analyze and characterize neurodegenerative and central nervous system diseases in the future.

REFERENCES

Azami, H., Rostaghi, M., Abasolo, D., & Escudero, J. (2017). Refined Composite Multiscale Dispersion Entropy and its Application to Biomedical Signals. *IEEE Transactions on Biomedical Engineering*, *64*(12), 2872-2879. https://doi.org/10.1109/tbme.2017.2679136

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, *1*(8476), 307-310.

Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. *Sensors*, *18*(3), 873. https://doi.org/10.3390/s18030873

Charmant, J., & Contributors.,. (2021). *"Kinovea"*. In

Christianson, M., Leathem, J. (2004). Development and standardisation of the Computerised Finger Tapping Test: Comparision with other finger tapping instruments. *New Zealand Journal of Psychology*, *33*.

Costa, M., Goldberger, A. L., & Peng, C. K. (2005). Multiscale entropy analysis of biological signals. *Phys Rev E Stat Nonlin Soft Matter Phys*, *71*(2 Pt 1), 021906. https://doi.org/10.1103/PhysRevE.71.021906

Costa, M. D., & Goldberger, A. L. (2015). Generalized Multiscale Entropy Analysis: Application to Quantifying the Complex Volatility of Human Heartbeat Time Series. *Entropy (Basel)*, *17*(3), 1197-1203. https://doi.org/10.3390/e17031197

Doğan, N. (2018). Bland-Altman analysis: A paradigm to understand correlation and agreement. *Turk J Emerg Med*, *18*(4), 139-141. https://doi.org/10.1016/j.tjem.2018.09.001

Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochemia Medica*, *25*(2), 141-151. https://doi.org/10.11613/bm.2015.015

Incagnoli, T. M. G., G. (1997). *Contemporary Approaches to Neuropsychological Assessment*. Plenum Press. https://doi.org/10.1007/978-1-4757-9820-3

Kalra, A. (2017). Decoding the Bland–Altman plot: Basic review. *Journal of the Practice of Cardiovascular Sciences*, *3*, 36 - 38.

Klay, M. (2021). *YAT*. In (Version 2.4.1)

MATLAB. (2021). *Natick, Massachusetts: The MatWorks, Inc*. In (Version R2021a)

Reitan, R. M., & Wolfson, D. (1985). *The Halstead-Reitan neuropsychological test battery: theory and clinical interpretation*. Tucson, Ariz.: Neuropsychology Press.

Roalf, D. R., Rupert, P., Mechanic-Hamilton, D., Brennan, L., Duda, J. E., Weintraub, D., Trojanowski, J. Q., Wolk, D., & Moberg, P. J. (2018). Quantitative assessment of finger tapping characteristics in mild cognitive impairment, Alzheimer's disease, and Parkinson's disease. *Journal of Neurology*, *265*(6), 1365-1375. https://doi.org/10.1007/s00415-018-8841-8

Schmidt, R., Lee, T., Winstein, C., Wulf, G., & Zelaznik, H. (2019). *Motor Control and Learning: A Behavioral Emphasis* (6th ed.).

Sedgwick, P. (2013). Limits of agreement (Bland-Altman method). *Bmj*, *346*, f1630. https://doi.org/10.1136/bmj.f1630

Suzumura, S., Osawa, A., Nagahama, T., Kondo, I., Sano, Y., & Kandori, A. (2016). Assessment of finger motor skills in individuals with mild cognitive impairment and patients with Alzheimer's disease: Relationship between finger-to-thumb tapping and cognitive function. *Japanese Journal of Comprehensive Rehabilitation Science*, *7*(0), 19-28. https://doi.org/10.11336/jjcrs.7.19

CHAPTER III

COMPLEXITY OF FINE MOTOR CONTROL IN FINGER TAPPING TEST AND GROSS MOTOR CONTROL IN GAIT AND SIT-AND-STAND TEST WITH FIBROMYALGIA PATIENTS: A RETROSPECTIVE CROSS-SECTIONAL STUDY

Abstract

The finger tapping test evaluates fine motor dysfunctions, and although it is usually used to assess neurodegenerative diseases (Roalf et al., 2018), it has also been applied to diseases of the central nervous system, such as Fibromyalgia (FM) (Gentile et al., 2020; Gentile et al., 2019). To be able to collect the execution process, we used an inertial sensor (IMU) to collect data during FTT, gait, and sit-and-stand tests. In order to analyze the execution process during tests, entropy in a single-scale and multiscale was used, allowing a possible characterization of different pathological states (Azami et al., 2017). In this sense, the aim of this study was to i) verify if the entropy values in fine and gross motor movements are higher in patients with Fibromyalgia; ii) verify the values of entropy between the single-scale and the multiscale algorithms, and; iii) verify if Finger Tapping Test, using this instrument and analysis, allows differentiating some characteristics of Fibromyalgia; iv) verify if entropy values in gross motor movements are higher in patients with Fibromyalgia than controls. The sample was composed of 20 females (46.150 ± 12.835 years old) divided into two groups, an experimental group with 10 FM subjects and a paired control group with 10 subjects without FM. Subjects were asked to perform the Finger Tapping Test (FTT), at a maximum speed with both hands. A rubber finger was used to attach the inertial sensor to the distal phalanx of the index finger. The results suggest that patients with FM have a controlled processing of information during the FTT task execution in both hands in order to simplify the task execution and correct the movement, while controls have more automatic processing when performing FTT with the preferred hand and have some difficulties in adapting the type of information processing when performing with the non-preferred hand. Gross motor control showed similar entropy values for both groups.

Keywords: Fibromyalgia; Fine Motor Control; Gross Motor Control; Entropy; Multiscale; Single-Scale; IMU

1. INTRODUCTION

Fine motor control can be defined as the ability to manipulate small objects, manual dexterity, and grapho-motricity. In addition to these capabilities, fine motor control also includes the ability to perform simple, repetitive, and speed-dominated movements, such as tapping a finger on a surface quickly and repetitively (Bondi et al., 2022; Martzog et al., 2019). A good example of this type of fine motor skill is the Finger Tapping Test (FTT), FTT evaluates fine motor impairment and is typically used to assess neurophysiological dysfunctions, such as Alzheimer's disease (AD), Parkinson's disease (PD) and dementia (Roalf et al., 2018). According to previous clinical studies, motor and sensory dysfunctions are present in their earliest stages in these diseases. This means that there may be the possibility to identify early stages of these conditions, with a non-invasively assessment and detect individuals at risk of neurodegenerative diseases (Albers et al., 2015; Suzumura et al., 2016). Following this, the FTT is a possible and viable test that can be used as a previous indicator for assessing the progression and identifying AD, PD, and dementia. Although FTT is mostly used in neurodegenerative diseases, it has also been applied to diseases of the central nervous system, such as Fibromyalgia (Gentile et al., 2020; Gentile et al., 2019).

More recently, Fibromyalgia has been assumed as a disease of the central nervous system that can be characterized by widespread pain, sensitivity to nonpainful stimuli, hypersensitivity to painful stimuli, and fine and gross motor control impairment (Gentile et al., 2019; Rasouli et al., 2017).

Recent studies (Gentile et al., 2020; Gentile et al., 2019) that used FTT as an assessment tool to evaluate patients with Fibromyalgia also used Electroencephalography (EEG)[4] and Functional Near-Infrared Spectroscopy (fNIRS)[5] to understand what happens in certain areas of the brain and motor cortex when these fine motor movements were performed at a slow or comfortable speed and at a maximum speed. These studies concluded that there were no differences in motor cortex activation areas in the slow movement speed, but when these FM patients performed de FTT at a maximum speed, the test revealed a dysfunctional activation and abnormal function of certain motor cortex areas. This fine motricity dysfunction could characterize FM patients, and it is possible that the FTT test

[4] EEG is a technique that measures electrical activity in the brain.

[5] FNIRS is a non-invasive technique that allows the real time detection of blood flow and metabolism changes in the cerebral cortical tissue

could facilitate a correct and more detailed diagnosis or even detect specific and different stages of this disease.

Some authors refer that fibromyalgia patients present a functional impairment in gross motor movements, such as gait (Carrasco-Vega et al., 2022; Heredia Jiménez et al., 2009; Rasouli et al., 2017). Gait is a highly important task that can provide important information about the patient's clinical state (Heredia-Jimenez et al., 2016). So, there is also a possibility to characterize Fibromyalgia through gross motor control analysis, using daily functional tasks like gait or sit and stand.

In order to be able to characterize different pathological states and identify neurodegenerative or central nervous system diseases, linear analysis may not be enough or adequate. Recently, non-linear measures have allowed a deeper motor control analysis, focusing on the process and on the quality of movement. One of these non-linear analysis measures is entropy (Azami et al., 2017).

There are many algorithms that can represent entropy on a single-scale or on a multiscale. Entropy measures on a single-scale can be characterized as the loss of information in a time series, and it can be used as a measure of uncertainty and irregularity of time series (Azami et al., 2017; Yentes & Raffalt, 2021). According to Yentes and Raffalt (2021), single-scale entropy is able to quantify the predictability and regularity of the next state of the system. Because of this association between entropy and predictability, when there is higher predictability, the new information you receive from the next states of the system is lower (Yentes & Raffalt, 2021). So, higher values of entropy reveal a higher uncertainty, while less entropy corresponds to lower irregularity or uncertainty of a time series (Azami et al., 2017).

However, as the name implies, multiscale entropy includes multiple timescales, allowing a greater understanding of the structural richness of a complex system. Complexity in the human body movement can be defined as a system that presents a deterministic origin and a structural richness (Yentes & Raffalt, 2021).

With the single-scale entropy measure, patients with some specific pathologies or diseases tend to be more predictable, meaning there are lower entropy values. However, with the multiscale entropy, these patients in some motor tasks tend to present a complexity loss, showing also lower entropy values (Azami et al., 2017; Lipsitz & Goldberger, 1992; Yentes & Raffalt, 2021).

The experimental questions in this study are: i) whether fibromyalgia patients have different predictability and complexity of movement control during the execution of speed-dominated fine motor tasks when compared to controls? ii) Are we able to characterize patients with Fibromyalgia by using different non-linear algorithms during the Finger Tapping Test? iii) Is it possible to analyze the predictability and complexity of gross motor movements with daily tasks and characterize fibromyalgia patients?

In order to be able to analyze the execution process, it is necessary to resort to instruments that allow the collection of more specific data and not just the number of touches in the surface. For this purpose, we used an inertial sensor (IMU) to collect data during FTT. Inertial sensors allow the collection of 3D linear acceleration and angular velocity data throughout the entire test in a more practical and precise way. To analyze the entire execution process through linear acceleration, it is necessary to look not only at the acceleration peaks but also at the acceleration time series. But why linear acceleration? In addition to being able to identify and detect acceleration peaks, which translates into touches on the surface, linear acceleration is more sensitive to oscillations, allowing a more detailed detection of any subtle changes in human movement (Camomilla et al., 2018).

According to these statements, the aims of this study were: i) to verify if entropy values in fine motor movements are higher in patients with Fibromyalgia when compared to the control group; ii) to verify the values of entropy between the single-scale and the multiscale algorithms, for patients with Fibromyalgia and for controls; iii) to verify if Finger Tapping Test, using inertial sensors and non-linear analysis, allows differentiating characteristics of fibromyalgia patients and; iv) to verify if entropy values in gross motor movements are higher in patients with Fibromyalgia than controls.

2. METHODS

2.1. Sample

20 female subjects (Table 2) with ages between 20 and 70 years old divided into two groups, an experimental group with 10 subjects diagnosed with Fibromyalgia by a qualified Rheumatologist and according to the standards defined by the American College of Rheumatology (ACR) (ACR, 2022); and a control group with 10 subjects without a diagnosis of Fibromyalgia or other diseases, paired in gender, age, preferred hand, height, weight and physical activity levels with the experimental group, these variables were collected through the application of a survey. All subjects signed an informed consent to

participate in the study, which has been approved by the (Nº 2A-2022 ESDRM) Ethics Committee of the Polytechnic Institute of Santarém. Subjects were recruited through virtual social platforms and belonged to the same region of Portugal.

Table 2. 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

2.2. Procedures

To assess fine motor control, the subjects were asked to perform the Finger Tapping Test (FTT), performing six trials at maximum speed for ten seconds per trial, starting with the preferred hand and repeating the entire process with the other hand. According to the Finger tapping test criteria, the score is the average number of the best five trials (Christianson, 2004). To collect data during the FTT, it was necessary to record all trials with a custom inertial sensor of the type MEMS model MPU9250, measuring Tridimensional (3D) (Figure 9) linear acceleration and angular velocity based on a specific program for this sensor.

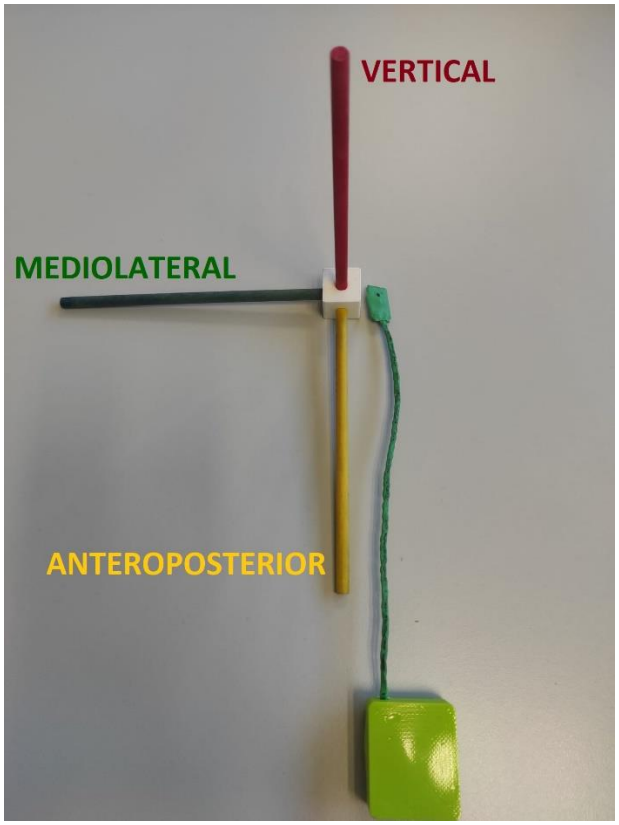

Figure 9. Inertial Sensor 3D axis

A rubber finger was used to attach the inertial sensor on the distal phalanx of the second finger. The inertial sensor was used to collect linear acceleration and angular velocity. Data was sent to the computer via Bluetooth and was received at the computer via a serial terminal (connection endpoint) (YAT) (Klay, 2021). Data were recorded in a text file (.txt). Then the files were sent to MATLAB (MATLAB, 2021) and SPSS (IBM, 2021) for data processing.

To assess gross motor control, the participants performed two different tasks, gait for two minutes at a comfortable speed and the 30-second chair sit-and-stand test (Rikli, 2013), where they had to stand and sit in a chair as many times as possible for 30 seconds, with their arms crossed above their chest. This tridimensional linear acceleration and angular velocity data were collected with an IMU (Movesense HR+, Movesense Ltd, Finland), which was placed on the right leg, above the malleolus of the fibula for the gait task and above the knee for sit and stand task (Camomilla et al., 2018). The IMU data was sent via Wi-fi to the computer and recorded in an excel file (.xls). Afterward the files were sent to MATLAB (MATLAB, 2021) and SPSS (IBM, 2021) for data processing.

2.3. Data Treatment and Statistical Analysis

The txt files of FTT and the excel files of gait and sit and stand were load to MATLAB in a custom script, where: the FTT collections were cutted and considered from the 1st acceleration peak in the finger's linear acceleration plot, corresponding to the first touch of the finger on the surface, until the tenth second of task execution; the gait and sit-and-stand collections were cutted and considered from the 1st acceleration peak corresponding to the first step in gait task and the first stand in sit-and-stand task to the last peak of acceleration in each task; linear acceleration was filtered with a butterworth digital filter of order 4 and a cutoff frequency of 30Hz; the "findpeaks" function in MATLAB was used to detect the touches on the surface and in this function the definitions of "MinPeakDistance" of 0,120s and the "MinPeakProminence" of 20% of the acceleration amplitude were applied, which means that the peaks below 120ms and with less than 20% of the acceleration amplitude were not detected; for FTT the average time between touches in each trial was calculated; the delay (or tau), and the embedding dimensions were calculated (UNO Biomechanics, 2022); the single scale entropy was calculated by the incremental entropy (Yentes & Raffalt, 2021).

In the analysis of very short signals, incremental entropy is a highly effective tool (Liu et al., 2016). Incremental entropy is more sensitive or has the ability to detect a subtle change in amplitude and in the structure and doesn't make any assumption on that, which means that it is applicable to different signals (Liu et al., 2016). The multiscale entropy was calculated by: – the refined-composite multiscale entropy (RCME) with the algorithm of Azami et al. (2017), through the EntropyHub MATLAB toolbox (Flood & Grimm, 2021). This algorithm was chosen because it is more recent and can solve some problems in entropy analysis than earlier algorithms. RCME is faster on long signals, more stable on noisy signals and can better discriminate elderly from young individuals and patients with neurodegenerative diseases from control subjects (Azami et al., 2017). Multiscale entropy analysis was used with 10 temporal scales, and its interpretation was performed through semi-quantitative analysis by observing the plots.

For statistical analysis, the distribution of variables under analysis was tested using the Kolmogorov-Smirnov test and was not assumed for all variables. Therefore, non-parametric tests were performed for comparisons between groups and between trials, using the U Mann-Whitney and Kruskal-Wallis tests, respectively. Comparison between hands was performed through the test of Wilcoxon. The effect sizes were calculated using Cohen's d algorithm, according to Fields (2018).

Considering that the demand and duration of used FTT protocol could introduce bias in the results of this test (e.g., caused by fatigue), it was necessary to check if there were any differences between trials of both hands (Table 3).

Table 3. Characterization of Variables: Number of touches on the surface; Time between touches; Incremental Entropy 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 Hand	**Nbeats**	45,0	12,7	46,2	9,6	46,5	10,0	47,0	9,9	46,7	8,0	48,9	9,2	1,15	0,95
		Tbeats	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,93	0,97
		Ent ML	3,9	0,2	4,0	0,2	3,9	0,1	3,9	0,1	3,9	0,1	3,9	0,1	0,68	0,98
		Ent AP	4,0	0,1	4,0	0,1	4,0	0,2	4,0	0,2	3,9	0,2	4,0	0,2	1,94	0,86
		Ent V	3,9	0,2	4,0	0,1	3,9	0,2	4,0	0,2	3,9	0,2	3,9	0,2	1,61	0,90
	Non-Preferred Hand	**Nbeats**	44,9	9,4	44,4	6,3	44,3	6,3	42,2	9,9	43,4	8,8	46,3	6,3	1,12	0,95
		Tbeats	0,2	0,1	0,2	0,0	0,2	0,0	0,2	0,1	0,2	0,1	0,2	0,0	1,08	0,96
		Ent ML	3,9	0,1	3,9	0,1	3,9	0,1	3,9	0,1	3,9	0,1	3,9	0,1	1,05	0,96
		Ent AP	4,0	0,1	4,0	0,1	3,9	0,1	3,9	0,1	3,9	0,1	3,9	0,1	3,88	0,57
		Ent V	3,9	0,1	4,0	0,1	3,9	0,2	4,0	0,1	3,9	0,1	3,9	0,1	1,13	0,95
Control Group	Preferred Hand	**Nbeats**	49,6	6,1	47,8	7,8	49,8	5,2	49,5	4,8	47,3	7,5	48,9	3,6	0,56	0,99
		Tbeats	0,2	0,0	0,2	0,0	0,2	0,0	0,2	0,0	0,2	0,0	0,2	0,0	0,89	0,97
		Ent ML	4,0	0,1	3,9	0,1	4,0	0,1	3,9	0,1	4,0	0,1	4,0	0,1	2,99	0,70
		Ent AP	3,9	0,2	3,9	0,2	3,9	0,2	3,9	0,2	3,9	0,2	3,9	0,2	0,78	0,98
		Ent V	4,0	0,1	4,0	0,1	4,0	0,1	3,9	0,1	4,0	0,1	4,0	0,1	1,04	0,96
	Non-Preferred Hand	**Nbeats**	45,9	5,4	46,0	4,5	46,7	3,4	44,7	6,8	46,5	7,3	48,1	5,0	2,00	0,85
		Tbeats	0,2	0,0	0,2	0,0	0,2	0,0	0,2	0,0	0,2	0,0	0,2	0,0	1,76	0,88
		Ent ML	4,0	0,1	3,9	0,1	3,9	0,1	3,9	0,1	3,9	0,1	3,9	0,1	2,81	0,73
		Ent AP	3,9	0,2	3,9	0,2	3,9	0,1	3,9	0,2	3,9	0,2	3,9	0,2	0,90	0,97
		Ent V	3,9	0,1	4,0	0,1	4,0	0,1	4,0	0,1	4,0	0,1	4,0	0,1	1,20	0,95

Nbeats – Number of touches on the surface; Tbeats – Time between touches; Ent ML – Incremental entropy for mediolateral axis; Ent AP – Incremental entropy for anteroposterior axis; Ent V – Incremental entropy for vertical axis; M – Mean; SD – Standard Deviation; H – Kruskal-Wallis; Sig. – Significance level.

As a result of this analysis, it was verified that there were no significant differences between trials for the number of touches on the surface, for the mean time between touches, and tridimensional incremental entropy, either for the fibromyalgia group and for control group. These results showed that the demand and duration of the FTT protocol seem to be adequate to apply the test.

3. RESULTS

3.1. Fine Motor Control

In Table 4 are presented the values for the statistical analysis and significance level for the variables of number of touches on the surface, time between touches and mediolateral (ML), anteroposterior (AP) and vertical (V) incremental entropy, between hand and per group.

Table 4. Characterization of variables for statistical tests and significant values: number of touches; time between touches; incremental entropy for mediolateral, anteroposterior and vertical axis, between hands and per group. In bold are the variables with significant differences.

Group/Hand		Preferred		Non-Preferred		Test Statistics		
		Mean	SD	Mean	SD	Z	Sig.	Effect Size
Fibromyalgia Group	Nbeats	**46.678**	**9.646**	**44.220**	**7.757**	**-2.814**	**0.005**	**0.890**
	Tbeats	**0.225**	**0.063**	**0.232**	**0.045**	**-2.355**	**0.019**	**0.745**
	Ent ML	3.932	0.142	3.903	0.112	-1.487	0.137	
	Ent AP	**3.964**	**0.144**	**3.925**	**0.101**	**-2.589**	**0.010**	**0.819**
	Ent V	3.940	0.155	3.934	0.127	-0.823	0.411	
Control Group	Nbeats	**48.817**	**5.850**	**46.317**	**5.423**	**-3.319**	**0.001**	**1.000**
	Tbeats	**0.207**	**0.029**	**0.218**	**0.030**	**-2.746**	**0.006**	**0.868**
	Ent ML	3.942	0.098	3.924	0.097	-1.266	0.205	
	Ent AP	3.916	0.164	3.888	0.168	-1.369	0.171	
	Ent V	3.971	0.116	3.975	0.124	-0.861	0.389	

Nbeats – number of touches in the surface; Tbeats – time between touches; Ent ML – incremental entropy for mediolateral axis; Ent AP – incremental entropy for anteroposterior axis; Ent V – incremental entropy for vertical axis; SD – standard deviation; Z - statistical Z test - Wilcoxon; Sig. – significance level.

In fibromyalgia group, there were verified differences in the number of touches, the time between touches, and the anteroposterior incremental entropy. The number of touches was significantly lower in the non-preferred hand and significantly higher in the preferred one (Z=-2.814, p=0.005, r=0.890). Also, the time between touches and the incremental entropy for the anteroposterior axis was significantly higher in the preferred hand and lower in the non-preferred one (Z=-2.355, p=0.019, r=0.745 and Z=-2.589, p=0.010, r=0.819, respectively). In the control group, there were significant differences in the number and time between touches but no differences in incremental entropy. The number of touches was significantly higher in the preferred hand and lower in the non-preferred hand (Z=-3.319, p=0.001, r=1.000), and the time between touches was significantly higher in the non-preferred hand and lower in the preferred one (Z=-2.746, p=0.006, r=0.868). The effect size was calculated for the variables with significant differences, showing a large effect (Fields, 2018).

Regarding comparisons between groups, in Table 5 are presented the values for the statistical analysis and significance level for the same variables, the number of touches in the surface, time between touches and mediolateral, anteroposterior and vertical incremental entropy, between group and per hand.

Table 5. Characterization of Variables for statistical tests and significant values: number of touches; time between touches; incremental entropy for mediolateral, anteroposterior and vertical axis, between groups and per hand.

Hand/Group		Fibromyalgia		Control		Test Statistics	
		Mean	SD	Mean	SD	U	Sig.
Preferred	Nbeats	46.678	9.646	48.817	5.850	1582.5	0.318
	Tbeats	0.225	0.063	0.207	0.029	1595.0	0.352
	Ent ML	3.932	0.142	3.942	0.098	1757.0	0.945
	Ent AP	3.964	0.144	3.916	0.164	1510.0	0.167
	Ent V	3.940	0.155	3.971	0.116	1617.0	0.416
Non- Preferred	Nbeats	44.220	7.757	46.317	5.423	1477.5	0.120
	Tbeats	0.232	0.045	0.218	0.030	1460.0	0.099
	Ent ML	3.903	0.112	3.924	0.097	1570.0	0.288
	Ent AP	3.925	0.101	3.888	0.168	1668.0	0.588
	Ent V	3.934	0.127	3.975	0.124	1425.0	0.067

Nbeats – number of touches in the surface; Tbeats – time between touches; Ent ML – incremental entropy for mediolateral axis; Ent AP – incremental entropy for anteroposterior axis; Ent V – incremental entropy for vertical axis; SD – standard deviation; U – Mann-Whitney; Sig. – significance level.

Although there were no significant differences between the groups and per hand for any of the variables, FM patients showed less number of touches in the surface, higher time between touches, and less incremental entropy for mediolateral and vertical movements in both hands when compared to controls. In addition, FM patients showed higher anteroposterior incremental entropy in both hands than controls.

In addition to the analysis of the previous variables, Refined-Composite Multiscale Entropy was also calculated to analyze the complexity level for each hand and axis between fibromyalgia group and control group.

Regarding the multiscale entropy, the next plots presented in these results represent the entropy levels for each timescale, for each axis of the movement, for each hand and between both groups.

The plots a, b, and c of Figure 10 refer to the multiscale entropy values for the preferred hand on each axis, mediolateral, anteroposterior and vertical, respectively. These plots also show the comparison of entropy between groups, Fibromyalgia, and controls.

In these results, entropy values are higher in the control group than in the fibromyalgia group, for the preferred hand.

Scales of entropy values for the preferred hand vary between 0.000 and 0.500, which means that the vertical axis has higher entropy values, followed by the anteroposterior axis and, finally, the mediolateral axis.

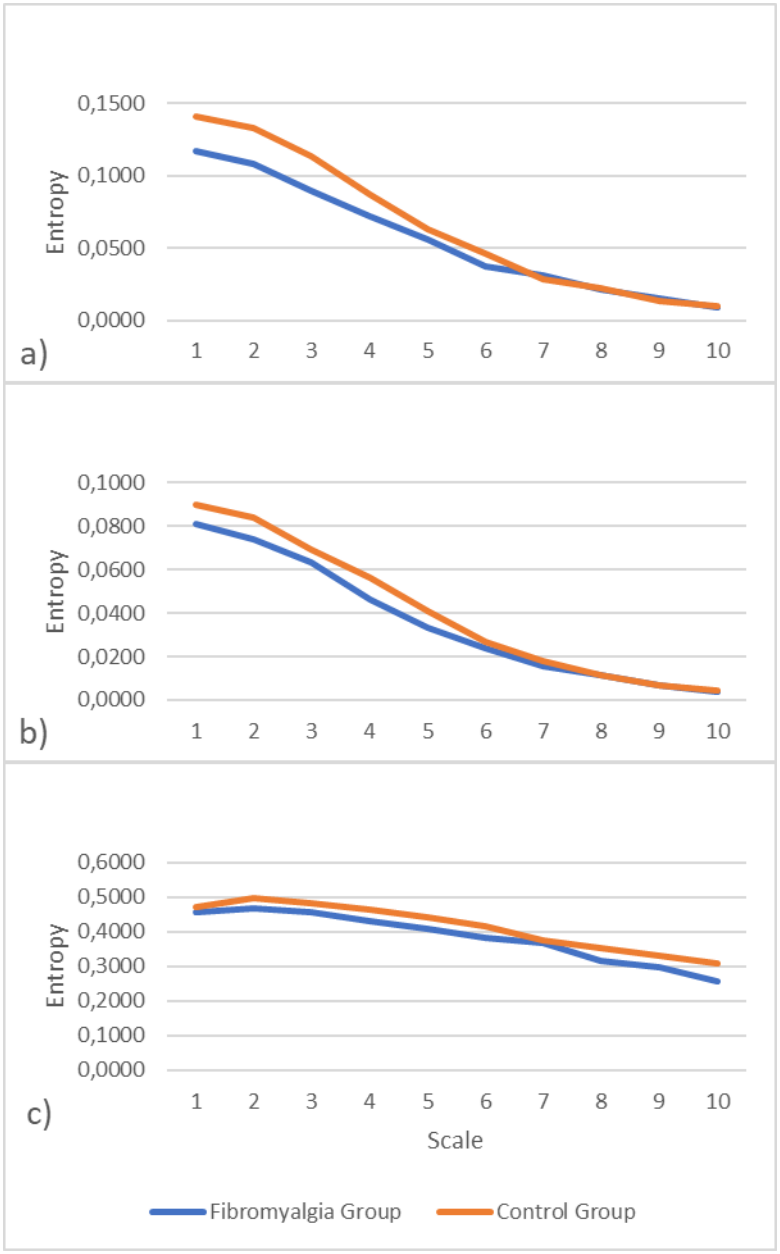

Figure 10. Refined-Composite Multiscale Entropy Values for the Preferred Hand Between Groups. a) represents the Entropy of Mediolateral accelerations, b) represents the Entropy of Anteroposterior accelerations, and, c) represents the Entropy of Vertical accelerations.

Plots d, e, and f of Figure 11 refer to the multiscale entropy values for the non-preferred hand on each axis, mediolateral, anteroposterior, and vertical, respectively. These plots also show the comparison of entropy between groups, Fibromyalgia and controls.

In these results, entropy values are higher in the fibromyalgia group than in the control group, for the non-preferred hand.

Scales of entropy values for the non-preferred hand vary between 0.000 and 0.550, which means that the anteroposterior axis has the lowest entropy values, followed by the mediolateral axis and the vertical axis has higher entropy values.

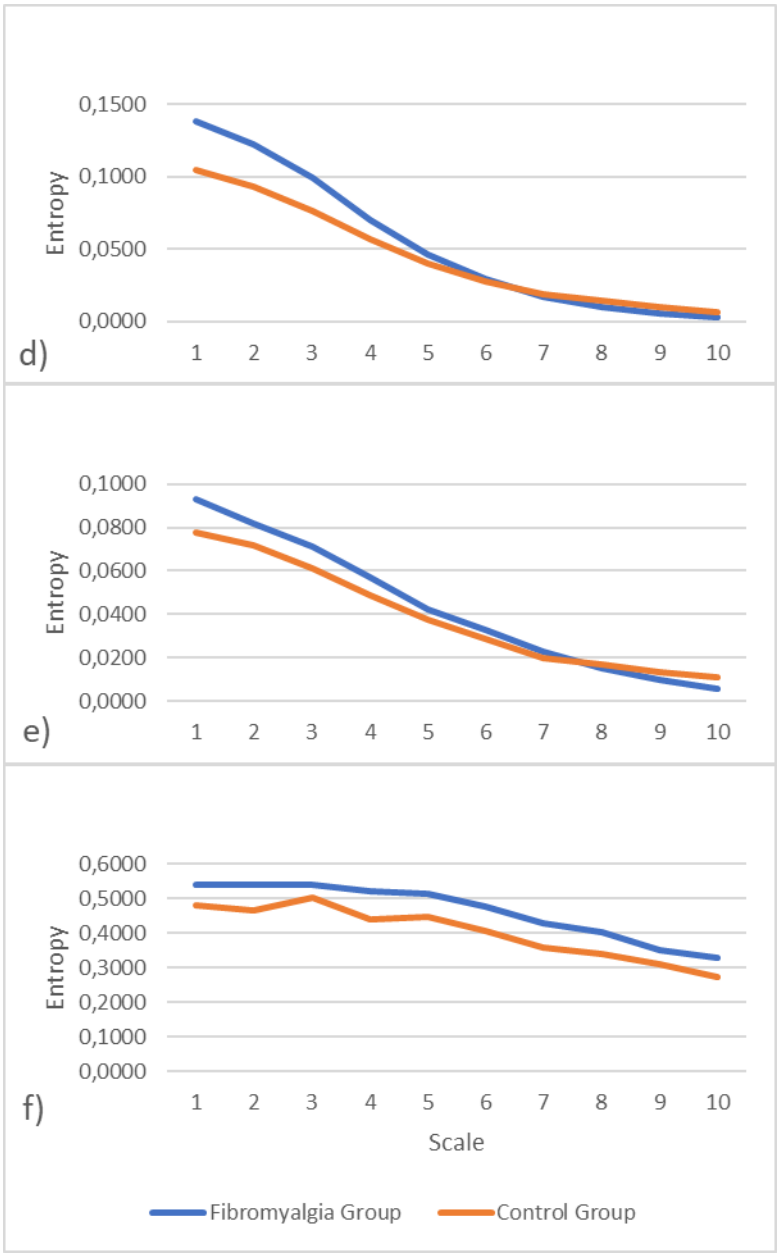

Figure 11. Refined-Composite Multiscale Entropy Values for the Non-Preferred Hand Between Groups. d) represents the Entropy of Mediolateral accelerations, e) represents the Entropy of Anteroposterior accelerations, and f) represents the Entropy of Vertical accelerations.

3.2. Gross Motor Control

The results that are represented in Table 6 show the values for the statistical analysis and significance level for the number of gait cycles, mediolateral, anteroposterior and vertical incremental entropy variables between groups and per task.

Table 6. Characterization of Variables for statistical tests and significant values: Number of cycles; Incremental entropy for mediolateral, anteroposterior and vertical axis, between group and per task.

Task/Group		Fibromyalgia		Control		Test Statistics	
		Mean	**SD**	**Mean**	**SD**	**U**	**Sig.**
Gait	Ncycles	144.100	29.076	140.000	16.780	42.000	0.579
	Ent ML	3.696	0.187	3.635	0.126	40.000	0.481
	Ent AP	3.977	0.120	4.012	0.132	42.000	0.579
	Ent V	4.110	0.066	4.078	0.067	38.000	0.393
Sit & Stand	Ncycles	32.500	4.403	33.900	5.646	49.000	0.971
	Ent ML	3.609	0.120	3.606	0.134	47.000	0.853
	Ent AP	3.590	0.085	3.509	0.118	35.000	0.280
	Ent V	3.690	0.047	3.713	0.139	37.000	0.353

Ncycles – number of gait cycles; Ent ML – incremental entropy for mediolateral axis; Ent AP – incremental entropy for anteroposterior axis; Ent V – incremental entropy for vertical axis; SD – standard deviation; U – Mann-Whitney; Sig. – significance level.

Although there were no significant differences in incremental entropy values between Fibromyalgia and controls in gait and sit and stand tasks, FM patients showed a higher number of gait cycles than controls.

In addition to the previous single-scale entropy and statistical analysis, Refined-Composite Multiscale Entropy was also calculated, allowing the analysis of the complexity levels in both tasks, gait, and sit and stand for both groups.

The plots a, b, and c of Figure 12 refer to the multiscale entropy values for gait task on each axis, mediolateral, anteroposterior and vertical, respectively. These plots also show the comparison of multiscale entropy between fibromyalgia and control group.

In these results, the entropy values are similar in both groups, overlapping in several moments of the gait task.

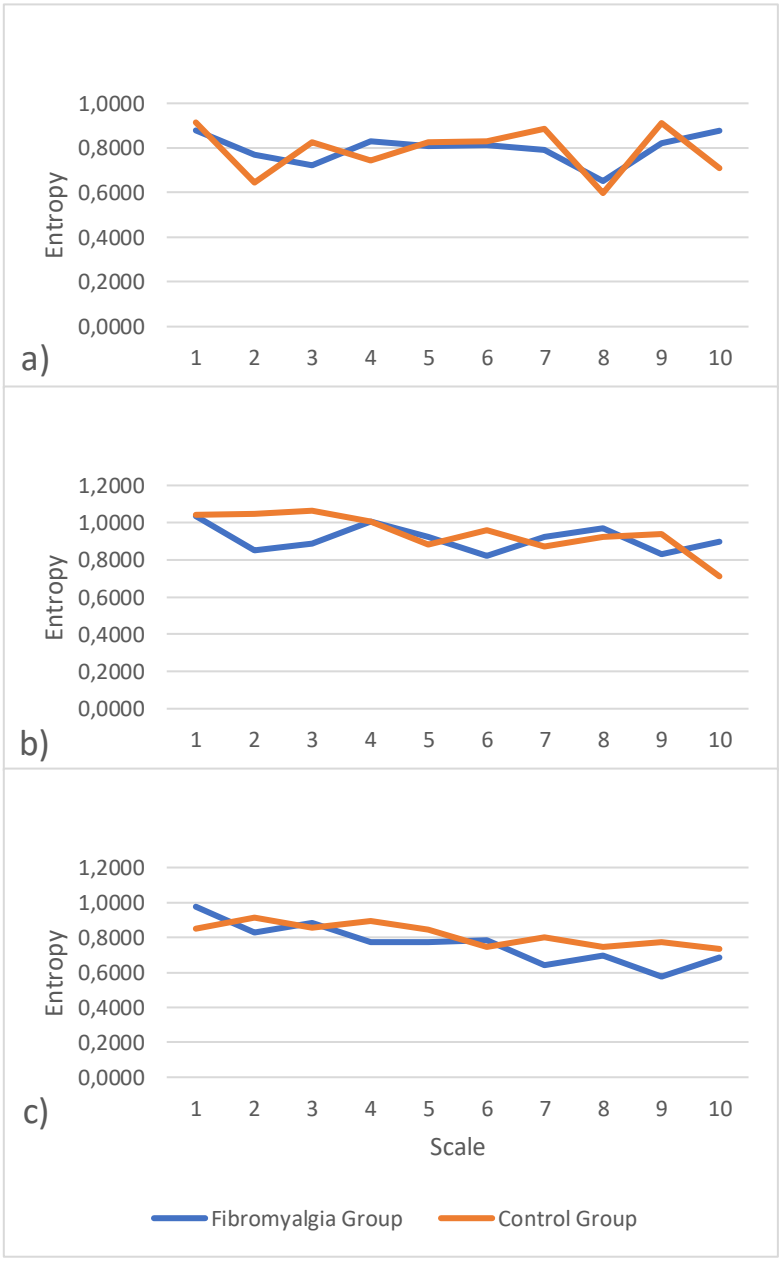

Figure 12. Refined-Composite Multiscale Entropy Values for the Gait task Between Groups. a) represents the Entropy of Mediolateral accelerations, b) represents the Entropy of Anteroposterior accelerations and, c) represents the Entropy of Vertical accelerations.

The plots d, e, and f of Figure 13 refer to the multiscale entropy values for sit and stand task on each axis, mediolateral, anteroposterior, and vertical, respectively. These plots also show the comparison of multiscale entropy between both groups.

In these results, like gait results, the entropy values are also similar in both groups, overlapping in several moments of the task.

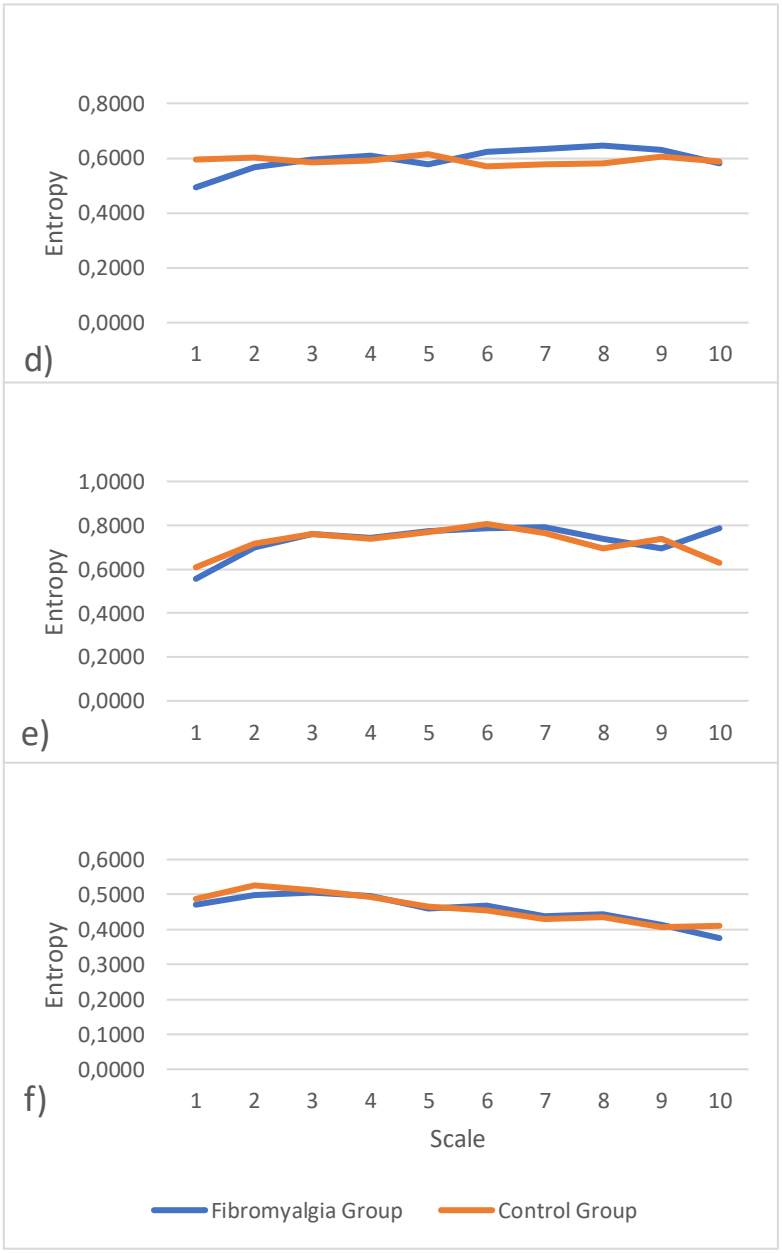

Figure 13. Refined-Composite Multiscale Entropy Values for Sit and Stand task Between Groups. a) represents the Entropy of Mediolateral accelerations, b) represents the Entropy of Anteroposterior accelerations and, c) represents the Entropy of Vertical accelerations

4. DISCUSSION

This retrospective cross-sectional design study intended to verify the values of entropy of single-scale and multiscale algorithms during the execution of fine and gross motor control tasks, for patients with Fibromyalgia and for controls, and compare them between both groups. Additionally, this study also aimed to verify if the Finger Tapping Test, with the use of inertial sensors, allows for differentiation characteristics of fibromyalgia patients.

The results point out that the control group performed more touches on the surface than FM patients and both groups performed a higher number of touches with the preferred hand. In both groups the time between touches was shorter in the preferred hand (Table 4), and because the controls make more touches on the surface, the time between touches is less in the control group than in the experimental group.

In the incremental entropy or single-scale entropy results, FM patients showed a significantly higher value of entropy in the anteroposterior movements, which indicates that FM patients are less predictable in these movements. This lower predictability means that in the anteroposterior movements, FM patients are more random or less probable with highly new information received from the next states of the system, which is usually seen in younger and healthy adults. With aging and impairment, gait or cyclic movement patterns tend to become more regular or more predictable. In accordance with this tendency, the single-scale results FM patients also showed lower entropy values in the vertical and mediolateral movements, meaning that they are more predictable when performing the FTT. Nonetheless, when the task demands are increased, like performing it at a maximum speed, it might lead to a more irregular pattern, as is shown in the anteroposterior movements (Yentes & Raffalt, 2021).

Fine motor skills are normally processed in the higher levels of the central nervous system (motor cortex and cerebellum) (Schmidt et al., 2019). According to the results, patients with Fibromyalgia showed a loss of complexity compared to individuals without Fibromyalgia when performing the FTT with the preferred hand. This could indicate that controls might have a more automatic behavior when performing FTT with the preferred hand because when the “motor system uses a more automatic control mode and takes advantage of unconscious, fast, and reflexive motor control process, the result is a more effective, efficient, and fluid motion” (Schmidt et al., 2019). Considering that FM patients not only have lower RCME entropy, but also less number of touches, allow us to state that these patients are spending time receiving and processing feedback information, which allows them to determine movement error and program instructions to reduce that error.

In this situation system requires more time to process the stimulus and therefore produce a response, which leads us to refer that FM patients maintain their information processing conscious and controlled and, therefore, under the presence of a closed-loop model (Schmidt et al., 2019). Still in this line of thought, Welford (1952) refers that during the processing of the first stimulus, the second stimulus has to be delayed until the response of the first one starts to confirm if the movement is produced correctly before the second stimulus is processed. Interference will occur if these two signals are processed at the same time. This may be a possible explanation for a longer time between touches, as FM patients constantly try to correct the movement, but are unable to do it due to the speed of the task, leading to a simplification of the task, probably through the freezing of degrees of freedom (Bernstein, 1967). In fact, it could explain the loss of complexity verified, in our study, confirming a difficulty to adapt like happens in aging and disease states (Azami et al., 2017). For controls, considering the lower time between touches, it seems that the stages of information processing are not involved, meaning that these types of corrections are produced by reflexive mechanisms and that this information is probably processed in the lower levels of the central nervous system (spinal and nerve receptors) (Schmidt et al., 2019). Contrary to the preferred hand, FM patients showed higher complexity in the non-preferred hand than controls. The possible reason for these results is the fact that the non-preferred hand has less fine motor skills, that is, less dexterity and less coordination ability than the preferred hand (Vasconcelos, 2006). The controls present a more automatic behavior when executing the FTT with the preferred hand. However, when doing it with the non-preferred hand, they present greater difficulty in adapting the type of information processing and seem to pass from processing in the lower levels of the central nervous system (automatic) to controlled processing (higher levels of the central nervous system). This may be a typical characteristic of these populations considering the range of RCME values. Methodologically, performing the test with both hands, preferred and non-preferred, allows us to understand and characterize the groups, Fibromyalgia and control, hence, it makes perfect sense to apply the test in both hands.

This is one of the advantages of using inertial sensors for the Finger Tapping Test. We cannot collect this amount of information just with the number of touches on the surface and analyzing the vertical position in the Kinovea software doesn't give us this information either. It would only be possible if we filmed each attempt in the three planes of motion using 2 to 3 cameras, which means much more analysis time. The IMU allows us to carry out a detailed, three-dimensional analysis that is more practical, faster, and cheaper (Camomilla et al., 2018).

Otherwise, gross motor control results showed that there were no significant differences between fibromyalgia patients and controls in single-scale. Controls showed fewer gait cycles and a smaller standard deviation, meaning that they performed this task slower and more consistently. FM patients showed more gait cycles, performing this task with more rhythm, but when subtracting the standard deviation from the mean, FM actually has fewer gait cycles and is more heterogeneous according to what they feel, they are more different from each other. Controls maintain more or less the same gait pace. Future studies should analyze gait rhythm and stride length. And for multiscale entropy, the complexity levels are similar in both groups. This might indicate that entropy in a single-scale and multiscale could be better for analyzing fine motor impairment in these patients and that, when using this non-linear analysis, Fibromyalgia could be better characterized by analyzing fine motor control rather than gross motor control.

According to what was referred above, multiscale entropy seems to be the better option to characterize FM patients through fine motor analysis, and also, because gross motor skills are more automatic than fine motor skills, FTT seems to be a better option.

5. CONCLUSIONS

In conclusion, although traditional FTT has been successfully applied to people with neurodegenerative diseases, a 3D analysis with an inertial sensor brings new and important information during the execution of the movement and not just the result. These results, combined with non-linear analysis, could allow a better understanding and characterization of motor control processes for Fibromyalgia. With this data, it was possible to verify that FM patients have a lower number of touches on the surface and time between touches, in both hands when compared to controls. Showing a functional loss in fine motor skills. Fibromyalgia patients also present lower complexity in the preferred hand and higher complexity in the preferred hand when compared to the controls. The RCME results suggest that patients with FM have a controlled processing of information during the FTT task execution in both hands in order to simplify the task execution and correct the movement, while controls have more automatic processing when performing FTT with the preferred hand and have some difficulties in adapting the type of information processing when performing with the non-preferred hand.

6. LIMITATIONS

The limitations of this study can be based on the sample size and the fact that there may be individuals in the control group who have other pathologies or associated diseases and have not referred them or have not yet been diagnosed.

REFERENCES

ACR., A. C. o. R. (2022). *American College of Rheumatology*. American College of Rheumatology. Retrieved 17 dec 2022 from https://www.rheumatology.org/

Albers, M. W., Gilmore, G. C., Kaye, J., Murphy, C., Wingfield, A., Bennett, D. A., Boxer, A. L., Buchman, A. S., Cruickshanks, K. J., Devanand, D. P., Duffy, C. J., Gall, C. M., Gates, G. A., Granholm, A. C., Hensch, T., Holtzer, R., Hyman, B. T., Lin, F. R., McKee, A. C., Morris, J. C., Petersen, R. C., Silbert, L. C., Struble, R. G., Trojanowski, J. Q., Verghese, J., Wilson, D. A., Xu, S., & Zhang, L. I. (2015). At the interface of sensory and motor dysfunctions and Alzheimer's disease. *Alzheimer's & Dementia*, *11*(1), 70-98. https://doi.org/10.1016/j.jalz.2014.04.514

Azami, H., Rostaghi, M., Abasolo, D., & Escudero, J. (2017). Refined Composite Multiscale Dispersion Entropy and its Application to Biomedical Signals. *IEEE Transactions on Biomedical Engineering*, *64*(12), 2872-2879. https://doi.org/10.1109/tbme.2017.2679136

Bernstein, N. (1967). *The co-ordination and regulation of movements*. Pergamon Press.

Bondi, D., Robazza, C., Lange-Küttner, C., & Pietrangelo, T. (2022). Fine motor skills and motor control networking in developmental age. *American Journal of Human Biology*. https://doi.org/10.1002/ajhb.23758

Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. *Sensors*, *18*(3), 873. https://doi.org/10.3390/s18030873

Carrasco-Vega, E., Ruiz-Muñoz, M., Cuesta-Vargas, A., Romero-Galisteo, R. P., & González-Sánchez, M. (2022). Individuals with fibromyalgia have a different gait pattern and a reduced walk functional capacity: a systematic review with meta-analysis. *Peerj*, *10*, e12908. https://doi.org/10.7717/peerj.12908

Christianson, M., Leathem, J. (2004). Development and standardisation of the Computerised Finger Tapping Test: Comparision with other finger tapping instruments. *New Zealand Journal of Psychology*, *33*.

Fields, A. (2018). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). SAGE Publications Ltd.

Flood, M. W., & Grimm, B. (2021). EntropyHub: An open-source toolkit for entropic time series analysis. *Plos One*, *16*(11), e0259448. https://doi.org/10.1371/journal.pone.0259448

Gentile, E., Brunetti, A., Ricci, K., Delussi, M., Bevilacqua, V., & De Tommaso, M. (2020). Mutual interaction between motor cortex activation and pain in fibromyalgia: EEG-fNIRS study. *Plos One*, *15*(1), e0228158. https://doi.org/10.1371/journal.pone.0228158

Gentile, E., Ricci, K., Delussi, M., Brighina, F., & de Tommaso, M. (2019). Motor Cortex Function in Fibromyalgia: A Study by Functional Near-Infrared Spectroscopy. *Pain Research and Treatment*, *2019*, Article 2623161. https://doi.org/10.1155/2019/2623161

Heredia-Jimenez, J., Orantes-Gonzalez, E., & Soto-Hermoso, V. M. (2016). Variability of gait, bilateral coordination, and asymmetry in women with fibromyalgia. *Gait Posture*, *45*, 41-44. https://doi.org/10.1016/j.gaitpost.2016.01.008

Heredia Jiménez, J. M., Aparicio García-Molina, V. A., Porres Foulquie, J. M., Delgado Fernández, M., & Soto Hermoso, V. M. (2009). Spatial-temporal parameters of gait in women with fibromyalgia. *Clinical Rheumatology*, *28*(5), 595-598. https://doi.org/10.1007/s10067-009-1101-7

IBM. (2021). *SPSS Statistics - IBM Corporation and its licensors*. In

Klay, M. (2021). *YAT*. In (Version 2.4.1)

Lipsitz, L. A., & Goldberger, A. L. (1992). Loss of 'complexity' and aging. Potential applications of fractals and chaos theory to senescence. *Jama*, *267*(13), 1806-1809.

Liu, X., Jiang, A., Xu, N., & Xue, J. (2016). Increment Entropy as a Measure of Complexity for Time Series. *Entropy*, *18*(1), 22. https://doi.org/10.3390/e18010022

Martzog, P., Stoeger, H., & Suggate, S. (2019). Relations between Preschool Children's Fine Motor Skills and General Cognitive Abilities. *Journal of Cognition and Development*, *20*(4), 443-465. https://doi.org/10.1080/15248372.2019.1607862

MATLAB. (2021). *Natick, Massachusetts: The MatWorks, Inc*. In (Version R2021a)

Rasouli, O., Fors, E. A., Borchgrevink, P. C., Öhberg, F., & Stensdotter, A. K. (2017). Gross and fine motor function in fibromyalgia and chronic fatigue syndrome. *J Pain Res*, *10*, 303-309. https://doi.org/10.2147/jpr.S127038

Rikli, R., Jones, C., . (2013). *Senior Fitness Test Manual*.

Roalf, D. R., Rupert, P., Mechanic-Hamilton, D., Brennan, L., Duda, J. E., Weintraub, D., Trojanowski, J. Q., Wolk, D., & Moberg, P. J. (2018). Quantitative assessment of finger tapping characteristics in mild cognitive impairment, Alzheimer's disease, and Parkinson's disease. *Journal of Neurology*, *265*(6), 1365-1375. https://doi.org/10.1007/s00415-018-8841-8

Schmidt, R., Lee, T., Winstein, C., Wulf, G., & Zelaznik, H. (2019). *Motor Control and Learning: A Behavioral Emphasis* (6th ed.).

Suzumura, S., Osawa, A., Nagahama, T., Kondo, I., Sano, Y., & Kandori, A. (2016). Assessment of finger motor skills in individuals with mild cognitive impairment and patients with Alzheimer's disease: Relationship between finger-to-thumb tapping and cognitive function. *Japanese Journal of Comprehensive Rehabilitation Science*, *7*(0), 19-28. https://doi.org/10.11336/jjcrs.7.19

UNO Biomechanics. (2022). *Nonlinear Analysis Core Library*. GitHub. Retrieved December 19, 2022 from https://github.com/Nonlinear-Analysis-Core/NONANLibrary/releases/tag/2.2.0.0

Vasconcelos, O. (2006). {Aprendizagem motora , transferência bilateral e preferê}ncia manual. 37-40.

Welford, A. (1952). *The "psychological refractory period" and the timing of high-speed performance - a review and a theory.*

Yentes, J. M., & Raffalt, P. C. (2021). Entropy Analysis in Gait Research: Methodological Considerations and Recommendations. *Ann Biomed Eng*, *49*(3), 979-990. https://doi.org/10.1007/s10439-020-02616-8

CHAPTER IV

VARIABILITY OF GROSS AND FINE MOTOR CONTROL IN DIFFERENT TASKS IN INDIVIDUALS WITH FIBROMYALGIA: A RETROSPECTIVE CROSS-SECTIONAL STUDY

Abstract

Fibromyalgia (FM) is normally defined as a widespread pain syndrome or disease (Carrasco-Vega et al., 2022) that presents disturbances in gross and fine motor control (Rasouli et al., 2017). 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 (Carrasco-Vega et al., 2022). Measuring the spatial and temporal gait parameters or gait variability has been used to assess motor pathologies and identify gait disorders (Heredia-Jimenez et al., 2016). The Lyapunov exponent is a non-linear measure of variability, which quantifies the ability that the system has to attenuate small perturbances (Dingwell & Marin, 2006; Heredia-Jimenez et al., 2016), and there might be a relationship between balance and spatiotemporal gait parameters (Lewek et al., 2014). 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 (Rantalainen et al., 2020). 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 (Rikli, 2013); and to analyze fine motor control, they were asked to perform six trials of FTT test with both hands (Reitan & Wolfson, 1985). 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

1. INTRODUCTION

Fibromyalgia (FM) is normally defined as a non-inflammatory widespread pain syndrome or disease with central sensitization mechanisms (Carrasco-Vega et al., 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; A. 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 et al., 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 also indicate 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 et al., 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 reports from Heredia-Jimenez et al. (2016) that measuring the spatial and temporal gait parameters has been used to assess motor pathologies and identify gait disorders, being considered highly clinically relevant. These measurements of spatiotemporal parameters quantify gait variability. According to Rantalainen et al. (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 et al., 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 measures 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 et al. (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 et al. (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 were performed (Gentile et al., 2020; Gentile et al., 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.

2. METHODS

2.1. Sample

The sample for this study was composed of 20 female participants (Table 7), 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 7. 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

2.2. Procedures

To analyze gross motor skills, participants were asked to perform the gait task and the 30-seconds 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 for 2 minutes on a straight ground and at a comfortable speed for the practitioner (Figure 14) and, on the right thigh, above the knee, during the 30-second chair sit-and-stand test (Figure 15). This last test was carried out according to the Senior Fitness Test Battery (Rikli, 2013), and 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 14). 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) is 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 14. IMU Position in Gait Task

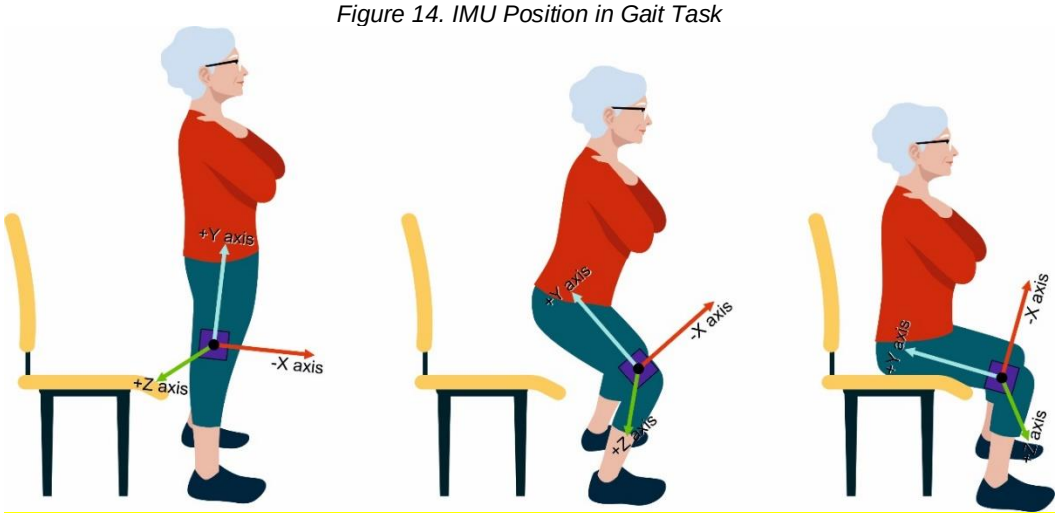

Figure 15. IMU Position in Sit and Stand Task

2.3. 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 16). In Figure 16, the raw data are represented by the dashed lines, and the filtered data corresponds to the colored lines for all movement axis.

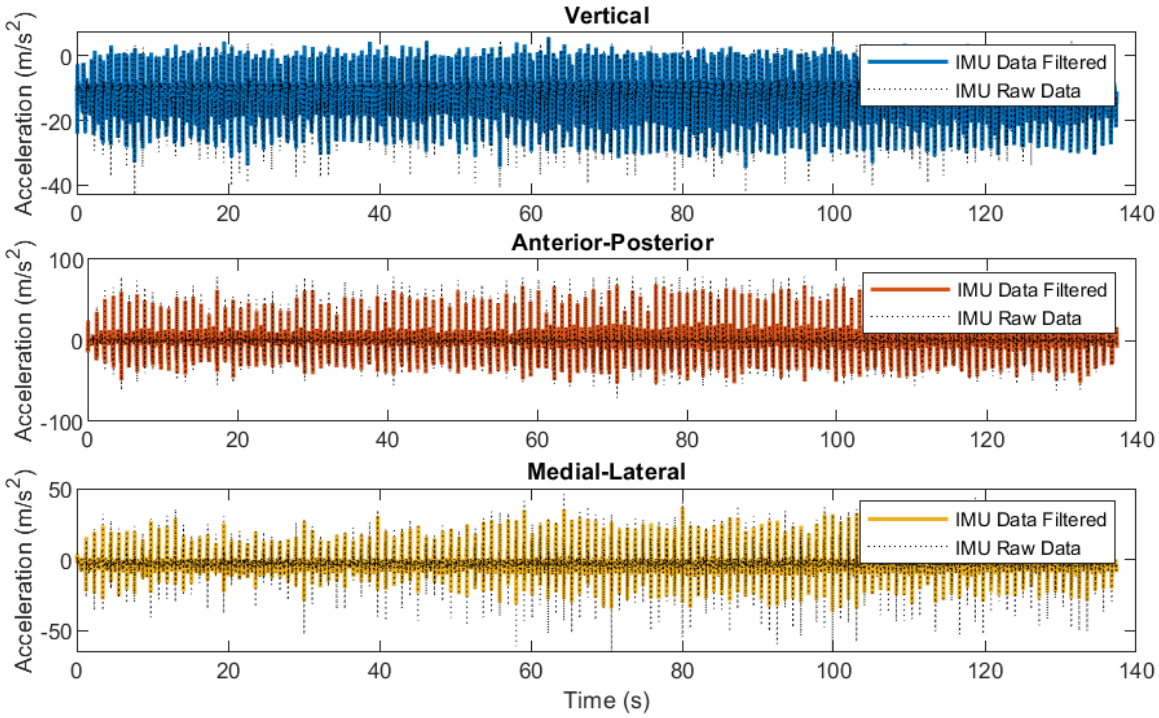

Figure 16. Differences between Raw (black line) and filtered data (color line), in gait task

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).

3. RESULTS

3.1. Gross Motor Control

Some results of the various stages of data treatment are presented below. Figure 17 and Figure 18 represents 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.

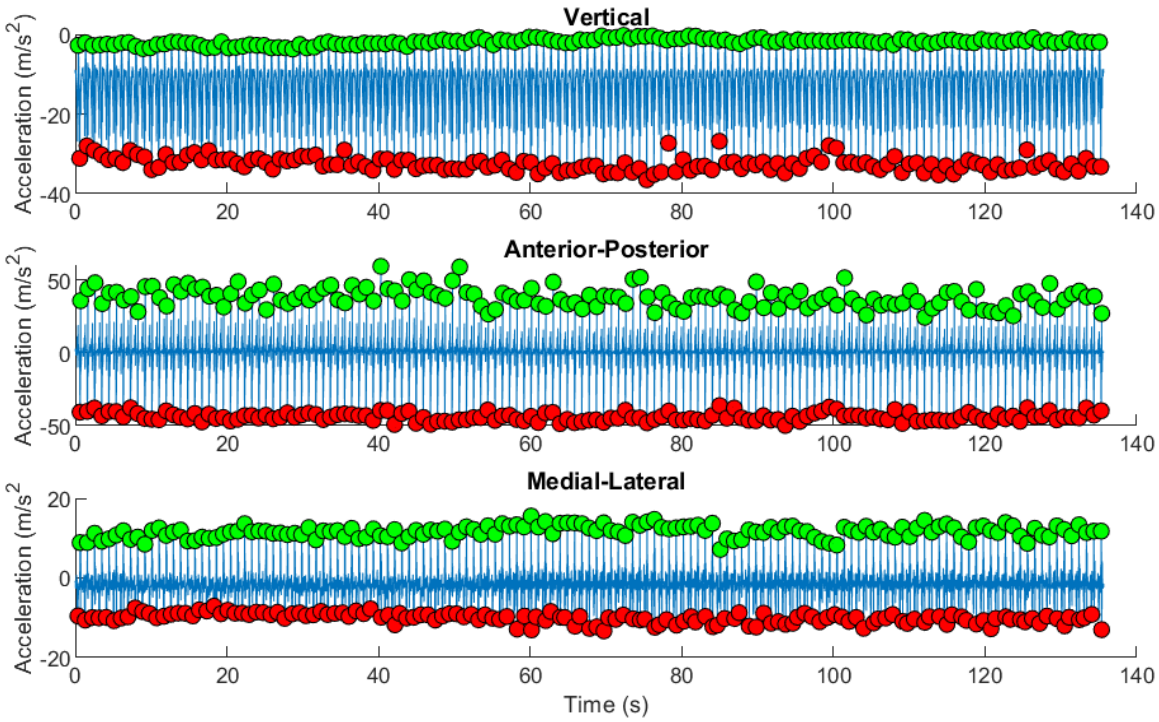

Figure 17. Tridimensional linear acceleration for the control group in gait analysis

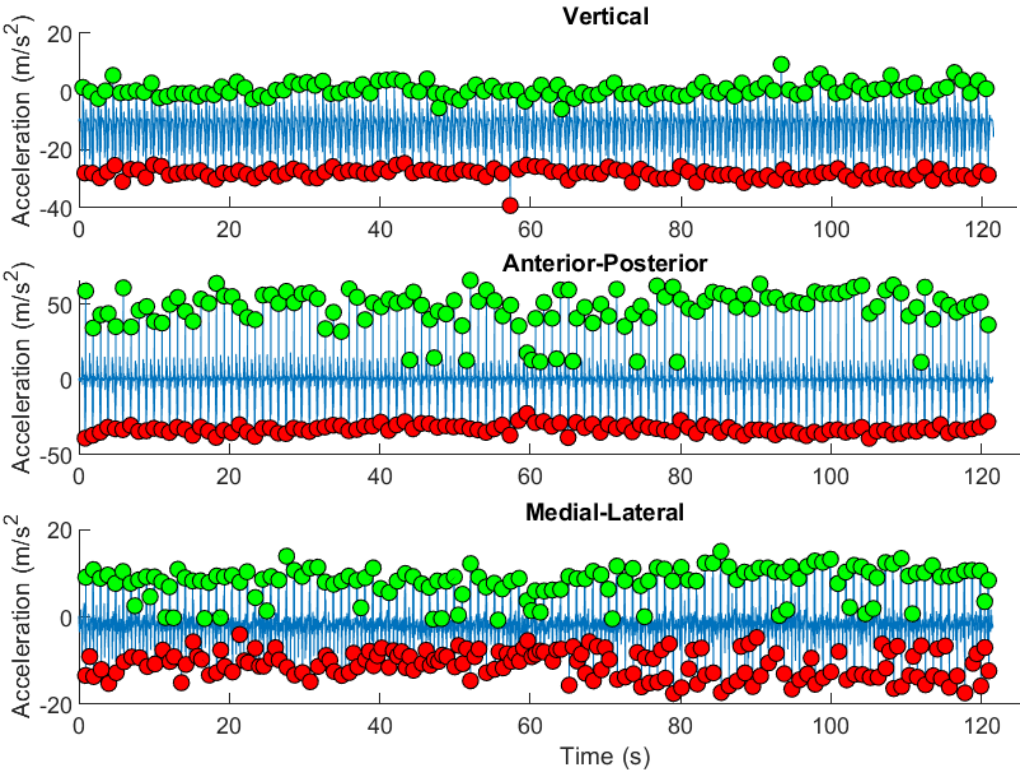

Figure 18. Tridimensional linear acceleration for fibromyalgia group in gait analysis

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 19 and Figure 20 represents the linear acceleration peaks (red and green dots) for vertical, anteroposterior, and mediolateral movements during sit and stand task in controls 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.

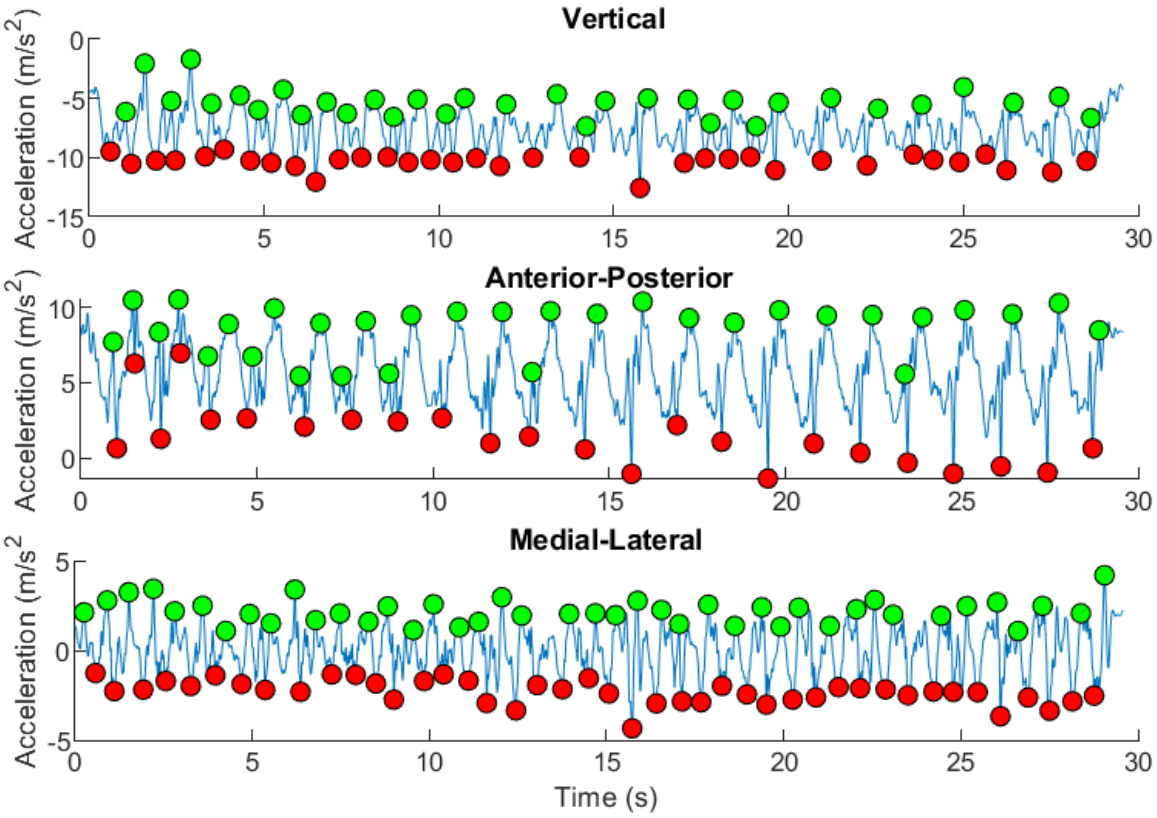

Figure 19. Tridimensional linear acceleration for the control group in sit and stand analysis

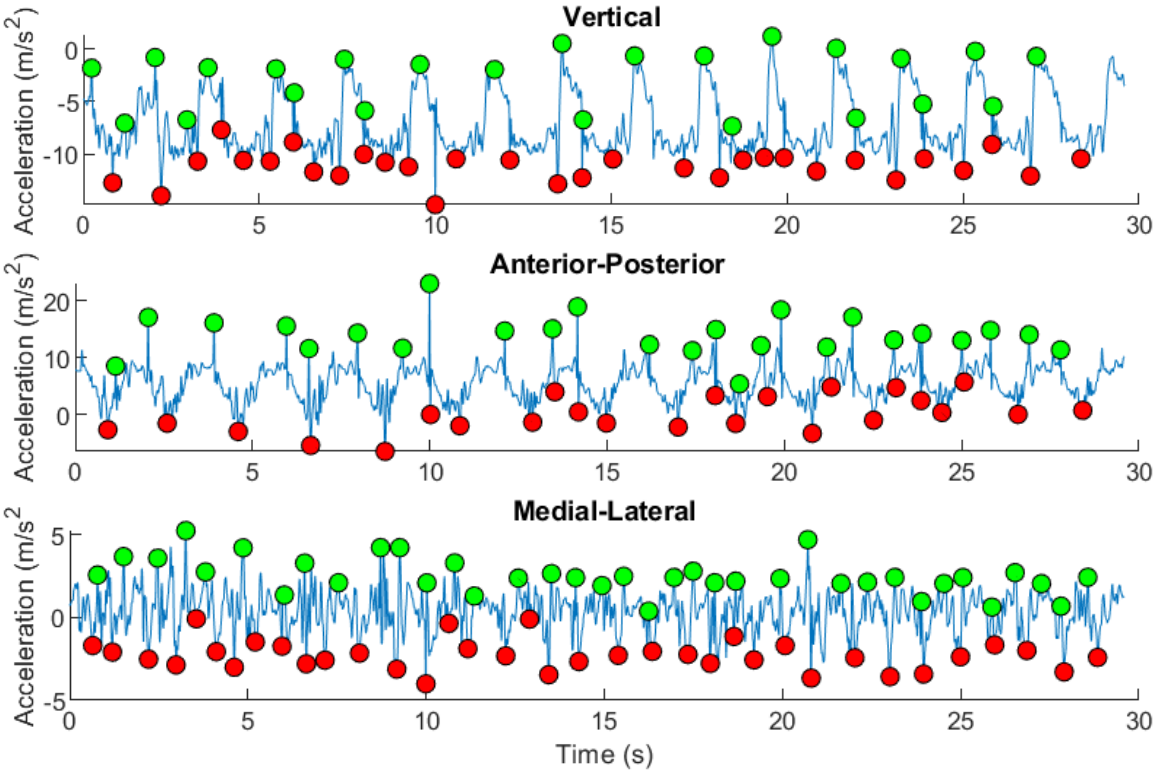

Figure 20. Tridimensional linear acceleration for fibromyalgia group in sit and stand analysis

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

Table 8. Statistical analysis in tridimensional acceleration Lyapunov values in gait and sit-and-stand tasks between groups. In bold are the variables with significant differences. 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

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).

3.2. Fine Motor Control

The results (Table 9) 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 9. 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 10 and Table 11 are presented the values for statistical analysis and significance level for the variables of Lyapunov mediolateral, anteroposterior and vertical values, between hands and per group and, between groups.

Table 10. 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 – Lyapunov anteroposterior; LyE Vert – Lyapunov Vertical; SD – standard deviation; U – Mann-Whitney; Sig. – significance Level

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

Table 11. 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

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 significant 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 (Figure 21) 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.

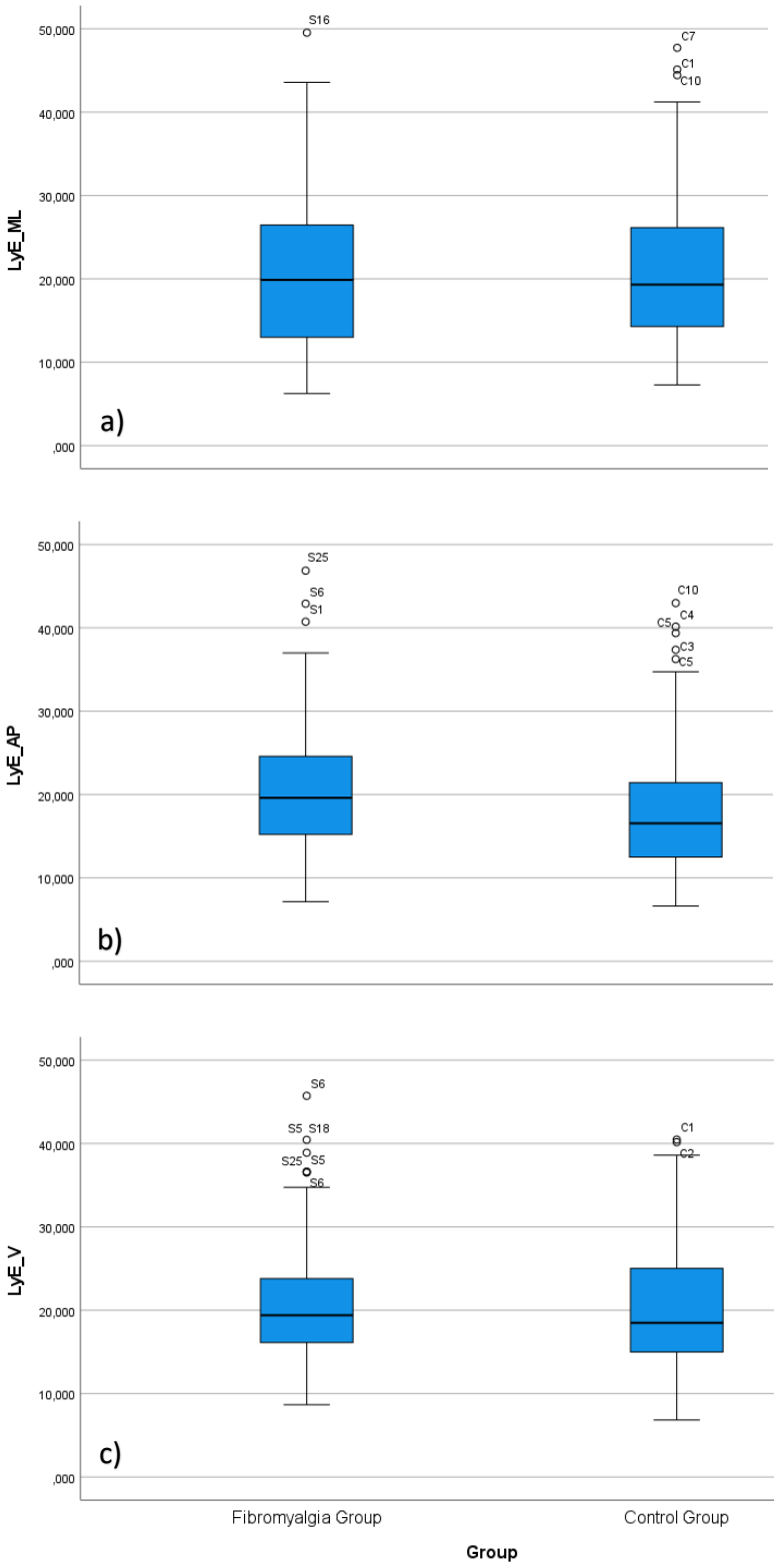

Figure 21. Statistical Descriptive Analysis for FTT Between Groups. Boxplots: a) represents the Lyapunov of Mediolateral accelerations, b) represents the Lyapunov of Anteroposterior accelerations, and c) represents the Lyapunov of Vertical accelerations

4. 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 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.

5. 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 in a more controlled way. These results may allow a better understanding and characterization of both the groups, Fibromyalgia, and control.

REFERENCES

ACR., A. C. o. R. (2022). *American College of Rheumatology*. American College of Rheumatology. Retrieved 17 dec 2022 from https://www.rheumatology.org/

ACSM. (2021). *American College of Sports Medicine - Guidelines for Exercise testing and Prescription* (Eleventh Edition ed.). Copyright.

Cagnie, B., Coppieters, I., Denecker, S., Six, J., Danneels, L., & Meeus, M. (2014). Central sensitization in fibromyalgia? A systematic review on structural and functional brain MRI. *Semin Arthritis Rheum*, *44*(1), 68-75. https://doi.org/10.1016/j.semarthrit.2014.01.001

Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. *Sensors*, *18*(3), 873. https://doi.org/10.3390/s18030873

Carrasco-Vega, E., Ruiz-Muñoz, M., Cuesta-Vargas, A., Romero-Galisteo, R. P., & González-Sánchez, M. (2022). Individuals with fibromyalgia have a different gait pattern and a reduced walk functional capacity: a systematic review with meta-analysis. *Peerj*, *10*, e12908. https://doi.org/10.7717/peerj.12908

Cerón-Lorente, L., Valenza, M. C., Pérez-Mármol, J. M., García-Ríos, M. D. C., Castro-Sánchez, A. M., & Aguilar-Ferrándiz, M. E. (2018). The influence of balance, physical disability, strength, mechanosensitivity and spinal mobility on physical activity at home, work and leisure time in women with fibromyalgia. *Clin Biomech (Bristol, Avon)*, *60*, 157-163. https://doi.org/10.1016/j.clinbiomech.2018.10.009

Christianson, M., Leathem, J. (2004). Development and standardisation of the Computerised Finger Tapping Test: Comparision with other finger tapping instruments. *New Zealand Journal of Psychology*, *33*.

Del-Moral-García, M., Obrero-Gaitán, E., Rodríguez-Almagro, D., Rodríguez-Huguet, M., Osuna-Pérez, M. C., & Lomas-Vega, R. (2020). Effectiveness of Active Therapy-Based Training to Improve the Balance in Patients with Fibromyalgia: A Systematic Review with Meta-Analysis. *J Clin Med*, *9*(11). https://doi.org/10.3390/jcm9113771

Dingwell, J. B., & Marin, L. C. (2006). Kinematic variability and local dynamic stability of upper body motions when walking at different speeds. *J Biomech*, *39*(3), 444-452. https://doi.org/10.1016/j.jbiomech.2004.12.014

Eken, A., Gökçay, D., Yılmaz, C., Baskak, B., Baltacı, A., & Kara, M. (2018). Association of Fine Motor Loss and Allodynia in Fibromyalgia: An fNIRS Study. *J Mot Behav*, *50*(6), 664-676. https://doi.org/10.1080/00222895.2017.1400947

Fields, A. (2018). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). SAGE Publications Ltd.

Gentile, E., Brunetti, A., Ricci, K., Delussi, M., Bevilacqua, V., & De Tommaso, M. (2020). Mutual interaction between motor cortex activation and pain in fibromyalgia: EEG-fNIRS study. *Plos One*, *15*(1), e0228158. https://doi.org/10.1371/journal.pone.0228158

Gentile, E., Ricci, K., Delussi, M., Brighina, F., & de Tommaso, M. (2019). Motor Cortex Function in Fibromyalgia: A Study by Functional Near-Infrared Spectroscopy. *Pain Research and Treatment*, *2019*, Article 2623161. https://doi.org/10.1155/2019/2623161

Heredia-Jimenez, J., Orantes-Gonzalez, E., & Soto-Hermoso, V. M. (2016). Variability of gait, bilateral coordination, and asymmetry in women with fibromyalgia. *Gait Posture*, *45*, 41-44. https://doi.org/10.1016/j.gaitpost.2016.01.008

IBM. (2021). *SPSS Statistics - IBM Corporation and its licensors*. In

Jones, K. D., Horak, F. B., Winters-Stone, K., Irvine, J. M., & Bennett, R. M. (2009). Fibromyalgia is associated with impaired balance and falls. *J Clin Rheumatol*, *15*(1), 16-21. https://doi.org/10.1097/RHU.0b013e318190f991

Klay, M. (2021). *YAT*. In (Version 2.4.1)

Lewek, M. D., Bradley, C. E., Wutzke, C. J., & Zinder, S. M. (2014). The relationship between spatiotemporal gait asymmetry and balance in individuals with chronic stroke. *J Appl Biomech*, *30*(1), 31-36. https://doi.org/10.1123/jab.2012-0208

MATLAB. (2021). *Natick, Massachusetts: The MatWorks, Inc*. In (Version R2021a)

Nijs, J., Meeus, M., Van Oosterwijck, J., Ickmans, K., Moorkens, G., Hans, G., & De Clerck, L. S. (2012). In the mind or in the brain? Scientific evidence for central sensitisation

in chronic fatigue syndrome. *European Journal of Clinical Investigation*, *42*(2), 203-212. https://doi.org/10.1111/j.1365-2362.2011.02575.x

Raffalt, P. C., Senderling, B., Stergiou, N. (2020). Filtering affects the calculation of the largest Lyapunov Exponent. *Computers in Biology and Medicine*, *122*. https://doi.org/10.1016/j.compbiomed.2020.103786

Rantalainen, T., Karavirta, L., Pirkola, H., Rantanen, T., & Linnamo, V. (2020). Gait Variability Using Waist- and Ankle-Worn Inertial Measurement Units in Healthy Older Adults. *Sensors*, *20*(10), 2858. https://doi.org/10.3390/s20102858

Rasouli, O., Fors, E. A., Borchgrevink, P. C., Öhberg, F., & Stensdotter, A. K. (2017). Gross and fine motor function in fibromyalgia and chronic fatigue syndrome. *J Pain Res*, *10*, 303-309. https://doi.org/10.2147/jpr.S127038

Reitan, R. M., & Wolfson, D. (1985). *The Halstead-Reitan neuropsychological test battery: theory and clinical interpretation*. Tucson, Ariz.: Neuropsychology Press.

Rikli, R., Jones, C., . (2013). *Senior Fitness Test Manual*.

Roalf, D. R., Rupert, P., Mechanic-Hamilton, D., Brennan, L., Duda, J. E., Weintraub, D., Trojanowski, J. Q., Wolk, D., & Moberg, P. J. (2018). Quantitative assessment of finger tapping characteristics in mild cognitive impairment, Alzheimer's disease, and Parkinson's disease. *Journal of Neurology*, *265*(6), 1365-1375. https://doi.org/10.1007/s00415-018-8841-8

Sommervoll, Y., Ettema, G., & Vereijken, B. (2011). Effects of age, task, and frequency on variability of finger tapping. *Percept Mot Skills*, *113*(2), 647-661. https://doi.org/10.2466/10.25.Pms.113.5.647-661

CHAPTER V

GENERAL DISCUSSION AND CONCLUSIONS

This dissertation presents three quasi-experimental studies that aimed to verify if Inertial Measurement Units (IMU) are instruments that can facilitate the applicability (Study 1), analysis, and interpretation of fine (Study 2) and gross (Study 3) motor control data of individuals with a fibromyalgia diagnosis.

In order to find new ways to evolve in new measurement methods and be able to keep pace with the technology evolution. There is often the need to compare existing methods with new ones and ensure an agreement between the two before using the new method in other research (Kalra, 2017). Because Fibromyalgia is a central nervous system disease (Cagnie et al., 2014), that presents a central pain processing dysfunction, and a functional impairment in fine motor skills (A. Eken et al., 2018), the finger tapping test (FTT) might allow a more detailed characterization of Fibromyalgia. Although FTT is normally used to diagnose neurodegenerative diseases (Roalf et al., 2018), it has also been applied in Fibromyalgia patients, along with EEG and fNIRS (Gentile et al., 2020; Gentile et al., 2019). So, to be able to characterize Fibromyalgia and also other central nervous system and neurodegenerative diseases in a more precise and rigorous way, there is the need to look not only at the results of the test but also at the process of execution. In this line of thought, in the first study, we demonstrated that the use of inertial sensors might be a viable alternative to the traditional method of the finger tapping test, since both have a great agreement between them. Allowing the collection and future analysis of other important information that we can only access by looking at the process and not just at the results. The inertial sensor not only allows a look at the process analysis but also allows a tridimensional analysis in a more practical way, which might be of great importance in future research. This is of most important information because it may allow the construction of an FTT analysis software in the future, considering all variables that the inertial sensor is able to collect.

In the second study, because there was a good level of agreement verified in the previous study, we were able to use this inertial sensor in the FTT in FM patients and controls and analyze the data with non-linear measures. The entropy analysis allowed a deeper motor control analysis, focusing on the process and quality of the movement (Azami et al., 2017). In this study, the Incremental Single-Scale and the Refined-Composite Multiscale Entropy (RCME) were used, and although single-scale presented a lower predictability in the front and back index movements in FM patients, this entropy algorithm showed some limitations in the results. Regarding what was observed during the test, patients with FM performed finger movement more slowly and touched the surface with more force. When touching

the surface with more force, they performed small traction movements, pulling the finger towards them.

Because information processing speed is crucial for motor control and fast motor responses (Rasouli et al., 2017), such as tapping a finger on the surface, the speed-dominated fine motor tasks are more demanding on the motor cortex (Aykut Eken et al., 2018; Gentile et al., 2020). Usually, these fine motor skills are processed at the higher levels of the central nervous system, but because FTT is a cyclic task, controls tend to have a more automatic behavior (processing at the lower levels of the central nervous system) when performing it with the preferred hand, resulting in a more fluid and efficient movement, while FM patients maintain their information processing more controlled, which might indicate that they have more difficulties to adapt to the demanding task, so, FM patients try to simplify and correct the movement probably by freezing degrees of freedom, resulting in less number of touches and a loss of complexity. When performing the task with the non-preferred hand, controls showed lower complexity than FM patients. The possible explanation for these results is that the non-preferred hand has less coordination than the preferred one, so controls have greater difficulties adapting the type of information processing from automatic processing to controlled processing. This may be a typical characteristic of these populations, allowing us to understand and characterize the groups, Fibromyalgia, and control.

As referred in this study, the use of inertial sensors brings crucial information for the Finger Tapping Test. The IMU allows us to carry out a detailed, three-dimensional analysis that is more practical, faster, and cheaper. And the use of IMU's along with RCME allows a possible characterization of fibromyalgia and control participants.

In this study, the results also showed that the plots for Refined-Composite Multiscale Entropy showed that the values presented in the results tend to stabilize, above six timescales, indicating that 10 timescales would not be necessary, six or seven scales might be enough. More studies with enlarged samples will be useful to test this hypothesis.

In addition to the loss of fine motor control, FM patients may also present a gross motor control impairment (Rasouli et al., 2017). In this second study, we were also able to analyze gait and sit and stand predictability and complexity. These entropy values showed similar results for both groups, which might represent that entropy might be more effective when used to measure fine motor control.

Regarding the third study, we resort to variability as a non-linear measure to analyze gait and the sit and stand as daily gross motor skills, and also FTT. In this study inertial sensors were also used to collect linear acceleration data.

According to the results in this study, FM patients present more gait variability in the anteroposterior and mediolateral movements than controls, this might indicate that FM participants have more difficulties in controlling these movements, so they present more oscillations and more instability in these axes. Maybe these results may be helpful in making adjustments to exercises and current daily activities for FM persons.

In the sit and stand task, FM presents a significantly higher Lyapunov value in the anteroposterior movements, which means that in these movements and in this task FM participants presented more instability and more difficulty in controlling these movements, so higher variability. But on the other hand, in the mediolateral and vertical movements, the values for FM group were lower when compared to the controls. Could it be possible that FM patients reorganize motor structures synchronization differently in order to compensate for pain and fatigue perception? These values should be considered in future studies and with other analysis methods. Fibromyalgia patients showed higher incremental entropy and significantly higher variability for anteroposterior movements in FTT, and they also showed higher variability for all degrees of freedom of both hands and higher complexity in the non-preferred and in finger tapping test than controls, which might represent that these patients have higher fine motor impairment than people without Fibromyalgia (Pérez-de-Heredia-Torres et al., 2013). These results for fine and gross motor control may allow a better understanding and characterization of both groups, Fibromyalgia and control. Although the results of fine motor control, with the use of inertial sensors combined with an analysis of RCME and variability, seem to be able to better characterize people with Fibromyalgia than an analysis of the RCME and variability of gross motor tasks. The use of other methods of linear or non-linear analysis should be performed for the analysis of fine and gross motor skills in future investigations.

In conclusion, the use of inertial sensors to collect data from fine and gross motor has a lot of potentials and brings innovation to exercise researchers and professionals. And can also be used in a clinical or practical context, regarding exercise prescription, it might be a great ally, as it is an easily accessible instrument. Studying the variability of fine and gross motor control allows a greater understanding of movement or task stability or control. During the process of writing and collecting data for this dissertation and during data treatment and analysis, one of the participants belonging to the control group, showed

abnormal results in the finger tapping test. This 50-year-old participant did not have any diagnosis of neurodegenerative and central nervous system disease. The unique situation that could justify these abnormalities in the test was the fact that this participant suffered a stroke in 2006, but did not have any visual impairments and only remembered that after being confronted by researchers asking if there were any problems in the past. These results presented the possibility that the use of FTT with IMU's and a non-linear analysis could be used in a practical context, not only to diagnose or characterize diseases but also to characterize the person and understand if the exercise prescription needs to be adequate to improve possible fine motor dysfunctions. In this line of thought, studying the individual's variability of gross motor tasks allows a detailed understanding of this person's ability to maintain stability in specific tasks, which might be important for exercise professionals. With this information, there is the possibility to prescribe exercise in a more individual and effective way.

Although the sample size in this dissertation is small, the effect size of most of the variables with significant differences is strong and therefore, the results are viable and of high importance (Fields, 2018).

REFERENCES

Azami, H., Rostaghi, M., Abasolo, D., & Escudero, J. (2017). Refined Composite Multiscale Dispersion Entropy and its Application to Biomedical Signals. *IEEE Transactions on Biomedical Engineering*, *64*(12), 2872-2879. https://doi.org/10.1109/tbme.2017.2679136

Cagnie, B., Coppieters, I., Denecker, S., Six, J., Danneels, L., & Meeus, M. (2014). Central sensitization in fibromyalgia? A systematic review on structural and functional brain MRI. *Semin Arthritis Rheum*, *44*(1), 68-75. https://doi.org/10.1016/j.semarthrit.2014.01.001

Eken, A., Gökçay, D., Yılmaz, C., Baskak, B., Baltacı, A., & Kara, M. (2018). Association of Fine Motor Loss and Allodynia in Fibromyalgia: An fNIRS Study. *J Mot Behav*, *50*(6), 664-676. https://doi.org/10.1080/00222895.2017.1400947

Eken, A., Gökçay, D., Yılmaz, C., Baskak, B., Baltacı, A., & Kara, M. (2018). Association of Fine Motor Loss and Allodynia in Fibromyalgia: An fNIRS Study. *Journal of Motor Behavior*, *50*(6), 664-676. https://doi.org/10.1080/00222895.2017.1400947

Fields, A. (2018). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). SAGE Publications Ltd.

Gentile, E., Brunetti, A., Ricci, K., Delussi, M., Bevilacqua, V., & De Tommaso, M. (2020). Mutual interaction between motor cortex activation and pain in fibromyalgia: EEG-fNIRS study. *Plos One*, *15*(1), e0228158. https://doi.org/10.1371/journal.pone.0228158

Gentile, E., Ricci, K., Delussi, M., Brighina, F., & de Tommaso, M. (2019). Motor Cortex Function in Fibromyalgia: A Study by Functional Near-Infrared Spectroscopy. *Pain Research and Treatment*, *2019*, Article 2623161. https://doi.org/10.1155/2019/2623161

Kalra, A. (2017). Decoding the Bland–Altman plot: Basic review. *Journal of the Practice of Cardiovascular Sciences*, *3*, 36 - 38.

Pérez-de-Heredia-Torres, M., Martínez-Piédrola, R. M., Cigarán-Méndez, M., Ortega-Santiago, R., & Fernández-de-Las-Peñas, C. (2013). Bilateral deficits in fine motor

control ability and manual dexterity in women with fibromyalgia syndrome. *Exp Brain Res*, *226*(1), 137-143. https://doi.org/10.1007/s00221-013-3417-4

Rasouli, O., Fors, E. A., Borchgrevink, P. C., Öhberg, F., & Stensdotter, A. K. (2017). Gross and fine motor function in fibromyalgia and chronic fatigue syndrome. *J Pain Res*, *10*, 303-309. https://doi.org/10.2147/jpr.S127038

Roalf, D. R., Rupert, P., Mechanic-Hamilton, D., Brennan, L., Duda, J. E., Weintraub, D., Trojanowski, J. Q., Wolk, D., & Moberg, P. J. (2018). Quantitative assessment of finger tapping characteristics in mild cognitive impairment, Alzheimer's disease, and Parkinson's disease. *Journal of Neurology*, *265*(6), 1365-1375. https://doi.org/10.1007/s00415-018-8841-8

BIBLIOGRAPHIC REFERENCES

ACR., A. C. o. R. (2022). *American College of Rheumatology*. American College of Rheumatology. Retrieved 17 dec 2022 from https://www.rheumatology.org/

ACSM. (2021). *American College of Sports Medicine - Guidelines for Exercise testing and Prescription* (Eleventh Edition ed.). Copyright.

Albers, M. W., Gilmore, G. C., Kaye, J., Murphy, C., Wingfield, A., Bennett, D. A., Boxer, A. L., Buchman, A. S., Cruickshanks, K. J., Devanand, D. P., Duffy, C. J., Gall, C. M., Gates, G. A., Granholm, A. C., Hensch, T., Holtzer, R., Hyman, B. T., Lin, F. R., McKee, A. C., Morris, J. C., Petersen, R. C., Silbert, L. C., Struble, R. G., Trojanowski, J. Q., Verghese, J., Wilson, D. A., Xu, S., & Zhang, L. I. (2015). At the interface of sensory and motor dysfunctions and Alzheimer's disease. *Alzheimer's & Dementia*, *11*(1), 70-98. https://doi.org/10.1016/j.jalz.2014.04.514

Azami, H., Rostaghi, M., Abasolo, D., & Escudero, J. (2017). Refined Composite Multiscale Dispersion Entropy and its Application to Biomedical Signals. *IEEE Transactions on Biomedical Engineering*, *64*(12), 2872-2879. https://doi.org/10.1109/tbme.2017.2679136

Bernstein, N. (1967). *The co-ordination and regulation of movements*. Pergamon Press.

Bhargava, J., & Hurley, J. A. (2022). Fibromyalgia. In *StatPearls*. StatPearls Publishing

Copyright © 2022, StatPearls Publishing LLC.

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, *1*(8476), 307-310.

Bondi, D., Robazza, C., Lange-Küttner, C., & Pietrangelo, T. (2022). Fine motor skills and motor control networking in developmental age. *American Journal of Human Biology*. https://doi.org/10.1002/ajhb.23758

Cagnie, B., Coppieters, I., Denecker, S., Six, J., Danneels, L., & Meeus, M. (2014). Central sensitization in fibromyalgia? A systematic review on structural and functional brain MRI. *Semin Arthritis Rheum*, *44*(1), 68-75. https://doi.org/10.1016/j.semarthrit.2014.01.001

Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. *Sensors*, *18*(3), 873. https://doi.org/10.3390/s18030873

Carrasco-Vega, E., Ruiz-Muñoz, M., Cuesta-Vargas, A., Romero-Galisteo, R. P., & González-Sánchez, M. (2022). Individuals with fibromyalgia have a different gait pattern and a reduced walk functional capacity: a systematic review with meta-analysis. *Peerj*, *10*, e12908. https://doi.org/10.7717/peerj.12908

Catela, D., Branco, M., Seabra, A., Mercê, C. (2015). *Comportamento Motor: Constrangimentos & Affordances*.

Cerón-Lorente, L., Valenza, M. C., Pérez-Mármol, J. M., García-Ríos, M. D. C., Castro-Sánchez, A. M., & Aguilar-Ferrándiz, M. E. (2018). The influence of balance, physical disability, strength, mechanosensitivity and spinal mobility on physical activity at home, work and leisure time in women with fibromyalgia. *Clin Biomech (Bristol, Avon)*, *60*, 157-163. https://doi.org/10.1016/j.clinbiomech.2018.10.009

Charmant, J., & Contributors.,. (2021). *"Kinovea"*. In

Christianson, M., Leathem, J. (2004). Development and standardisation of the Computerised Finger Tapping Test: Comparision with other finger tapping instruments. *New Zealand Journal of Psychology*, *33*.

Costa, M., Goldberger, A. L., & Peng, C. K. (2005). Multiscale entropy analysis of biological signals. *Phys Rev E Stat Nonlin Soft Matter Phys*, *71*(2 Pt 1), 021906. https://doi.org/10.1103/PhysRevE.71.021906

Costa, M. D., & Goldberger, A. L. (2015). Generalized Multiscale Entropy Analysis: Application to Quantifying the Complex Volatility of Human Heartbeat Time Series. *Entropy (Basel)*, *17*(3), 1197-1203. https://doi.org/10.3390/e17031197

Davids, K., Glazier, P., Ara??Jo, D., & Bartlett, R. (2003). Movement Systems as Dynamical Systems. *Sports Medicine*, *33*(4), 245-260. https://doi.org/10.2165/00007256-200333040-00001

Del-Moral-García, M., Obrero-Gaitán, E., Rodríguez-Almagro, D., Rodríguez-Huguet, M., Osuna-Pérez, M. C., & Lomas-Vega, R. (2020). Effectiveness of Active Therapy-Based Training to Improve the Balance in Patients with Fibromyalgia: A Systematic

Review with Meta-Analysis. *J Clin Med*, *9*(11). https://doi.org/10.3390/jcm9113771

Dingwell, J. B., & Marin, L. C. (2006). Kinematic variability and local dynamic stability of upper body motions when walking at different speeds. *J Biomech*, *39*(3), 444-452. https://doi.org/10.1016/j.jbiomech.2004.12.014

Doğan, N. (2018). Bland-Altman analysis: A paradigm to understand correlation and agreement. *Turk J Emerg Med*, *18*(4), 139-141. https://doi.org/10.1016/j.tjem.2018.09.001

Eken, A., Gökçay, D., Yılmaz, C., Baskak, B., Baltacı, A., & Kara, M. (2018). Association of Fine Motor Loss and Allodynia in Fibromyalgia: An fNIRS Study. *J Mot Behav*, *50*(6), 664-676. https://doi.org/10.1080/00222895.2017.1400947

Eken, A., Gökçay, D., Yılmaz, C., Baskak, B., Baltacı, A., & Kara, M. (2018). Association of Fine Motor Loss and Allodynia in Fibromyalgia: An fNIRS Study. *Journal of Motor Behavior*, *50*(6), 664-676. https://doi.org/10.1080/00222895.2017.1400947

Fields, A. (2018). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). SAGE Publications Ltd.

Flood, M. W., & Grimm, B. (2021). EntropyHub: An open-source toolkit for entropic time series analysis. *Plos One*, *16*(11), e0259448. https://doi.org/10.1371/journal.pone.0259448

Gentile, E., Brunetti, A., Ricci, K., Delussi, M., Bevilacqua, V., & De Tommaso, M. (2020). Mutual interaction between motor cortex activation and pain in fibromyalgia: EEG-fNIRS study. *Plos One*, *15*(1), e0228158. https://doi.org/10.1371/journal.pone.0228158

Gentile, E., Ricci, K., Delussi, M., Brighina, F., & de Tommaso, M. (2019). Motor Cortex Function in Fibromyalgia: A Study by Functional Near-Infrared Spectroscopy. *Pain Research and Treatment*, *2019*, Article 2623161. https://doi.org/10.1155/2019/2623161

Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochemia Medica*, *25*(2), 141-151. https://doi.org/10.11613/bm.2015.015

Goldfield, E. (1995). *Emergent Forms - Origins and Early Development of Human Action and Perception*. Oxford University Press, Inc.

Heredia-Jimenez, J., Orantes-Gonzalez, E., & Soto-Hermoso, V. M. (2016). Variability of gait, bilateral coordination, and asymmetry in women with fibromyalgia. *Gait Posture*, *45*, 41-44. https://doi.org/10.1016/j.gaitpost.2016.01.008

Heredia Jiménez, J. M., Aparicio García-Molina, V. A., Porres Foulquie, J. M., Delgado Fernández, M., & Soto Hermoso, V. M. (2009). Spatial-temporal parameters of gait in women with fibromyalgia. *Clinical Rheumatology*, *28*(5), 595-598. https://doi.org/10.1007/s10067-009-1101-7

IBM. (2021). *SPSS Statistics - IBM Corporation and its licensors*. In

Incagnoli, T. M. G., G. (1997). *Contemporary Approaches to Neuropsychological Assessment*. Plenum Press. https://doi.org/10.1007/978-1-4757-9820-3

Jones, K. D., Horak, F. B., Winters-Stone, K., Irvine, J. M., & Bennett, R. M. (2009). Fibromyalgia is associated with impaired balance and falls. *J Clin Rheumatol*, *15*(1), 16-21. https://doi.org/10.1097/RHU.0b013e318190f991

Kalra, A. (2017). Decoding the Bland–Altman plot: Basic review. *Journal of the Practice of Cardiovascular Sciences*, *3*, 36 - 38.

Kelso. (1995). *Dynamic Patterns*. MITT.

Klay, M. (2021). *YAT*. In (Version 2.4.1)

Lewek, M. D., Bradley, C. E., Wutzke, C. J., & Zinder, S. M. (2014). The relationship between spatiotemporal gait asymmetry and balance in individuals with chronic stroke. *J Appl Biomech*, *30*(1), 31-36. https://doi.org/10.1123/jab.2012-0208

Lipsitz, L. A., & Goldberger, A. L. (1992). Loss of 'complexity' and aging. Potential applications of fractals and chaos theory to senescence. *Jama*, *267*(13), 1806-1809.

Liu, X., Jiang, A., Xu, N., & Xue, J. (2016). Increment Entropy as a Measure of Complexity for Time Series. *Entropy*, *18*(1), 22. https://doi.org/10.3390/e18010022

Maffei, M. E. (2020). Fibromyalgia: Recent Advances in Diagnosis, Classification, Pharmacotherapy and Alternative Remedies. *International Journal of Molecular Sciences*, *21*(21), 7877. https://doi.org/10.3390/ijms21217877

Martzog, P., Stoeger, H., & Suggate, S. (2019). Relations between Preschool Children's Fine Motor Skills and General Cognitive Abilities. *Journal of Cognition and Development*, *20*(4), 443-465. https://doi.org/10.1080/15248372.2019.1607862

MATLAB. (2021). *Natick, Massachusetts: The MatWorks, Inc*. In (Version R2021a)

Mehdizadeh, S. (2018). The largest Lyapunov exponent of gait in young and elderly individuals: A systematic review. *Gait Posture*, *60*, 241-250. https://doi.org/10.1016/j.gaitpost.2017.12.016

Nijs, J., Meeus, M., Van Oosterwijck, J., Ickmans, K., Moorkens, G., Hans, G., & De Clerck, L. S. (2012). In the mind or in the brain? Scientific evidence for central sensitisation in chronic fatigue syndrome. *European Journal of Clinical Investigation*, *42*(2), 203-212. https://doi.org/10.1111/j.1365-2362.2011.02575.x

Pérez-de-Heredia-Torres, M., Martínez-Piédrola, R. M., Cigarán-Méndez, M., Ortega-Santiago, R., & Fernández-de-Las-Peñas, C. (2013). Bilateral deficits in fine motor control ability and manual dexterity in women with fibromyalgia syndrome. *Exp Brain Res*, *226*(1), 137-143. https://doi.org/10.1007/s00221-013-3417-4

Raffalt, P. C., Senderling, B., Stergiou, N. (2020). Filtering affects the calculation of the largest Lyapunov Exponent. *Computers in Biology and Medicine*, *122*. https://doi.org/10.1016/j.compbiomed.2020.103786

Rantalainen, T., Karavirta, L., Pirkola, H., Rantanen, T., & Linnamo, V. (2020). Gait Variability Using Waist- and Ankle-Worn Inertial Measurement Units in Healthy Older Adults. *Sensors*, *20*(10), 2858. https://doi.org/10.3390/s20102858

Rasouli, O., Fors, E. A., Borchgrevink, P. C., Öhberg, F., & Stensdotter, A. K. (2017). Gross and fine motor function in fibromyalgia and chronic fatigue syndrome. *J Pain Res*, *10*, 303-309. https://doi.org/10.2147/jpr.S127038

Reitan, R. M., & Wolfson, D. (1985). *The Halstead-Reitan neuropsychological test battery: theory and clinical interpretation*. Tucson, Ariz.: Neuropsychology Press.

Rikli, R., Jones, C., . (2013). *Senior Fitness Test Manual*.

Roalf, D. R., Rupert, P., Mechanic-Hamilton, D., Brennan, L., Duda, J. E., Weintraub, D., Trojanowski, J. Q., Wolk, D., & Moberg, P. J. (2018). Quantitative assessment of finger tapping characteristics in mild cognitive impairment, Alzheimer's disease, and Parkinson's disease. *Journal of Neurology*, *265*(6), 1365-1375. https://doi.org/10.1007/s00415-018-8841-8

Schmidt, R., Lee, T., Winstein, C., Wulf, G., & Zelaznik, H. (2019). *Motor Control and Learning: A Behavioral Emphasis* (6th ed.).

Sedgwick, P. (2013). Limits of agreement (Bland-Altman method). *Bmj*, *346*, f1630. https://doi.org/10.1136/bmj.f1630

Sommervoll, Y., Ettema, G., & Vereijken, B. (2011). Effects of age, task, and frequency on variability of finger tapping. *Percept Mot Skills*, *113*(2), 647-661. https://doi.org/10.2466/10.25.Pms.113.5.647-661

Suzumura, S., Osawa, A., Nagahama, T., Kondo, I., Sano, Y., & Kandori, A. (2016). Assessment of finger motor skills in individuals with mild cognitive impairment and patients with Alzheimer's disease: Relationship between finger-to-thumb tapping and cognitive function. *Japanese Journal of Comprehensive Rehabilitation Science*, *7*(0), 19-28. https://doi.org/10.11336/jjcrs.7.19

Turvey, M. T. (1990). Coordination. *American Psychologist*, *45*(8), 938-953.

UNO Biomechanics. (2022). *Nonlinear Analysis Core Library*. GitHub. Retrieved December 19, 2022 from https://github.com/Nonlinear-Analysis-Core/NONANLibrary/releases/tag/2.2.0.0

Vasconcelos, O. (2006). {Aprendizagem motora , transferência bilateral e preferê}ncia manual. 37-40.

Wang, S. M., Han, C., Lee, S. J., Patkar, A. A., Masand, P. S., & Pae, C. U. (2015). Fibromyalgia diagnosis: a review of the past, present and future. *Expert Rev Neurother*, *15*(6), 667-679. https://doi.org/10.1586/14737175.2015.1046841

Welford, A. (1952). *The "psychological refractory period" and the timing of high-speed performance - a review and a theory.*

Yentes, J. M., & Raffalt, P. C. (2021). Entropy Analysis in Gait Research: Methodological Considerations and Recommendations. *Ann Biomed Eng*, *49*(3), 979-990. https://doi.org/10.1007/s10439-020-02616-8

APPENDIXES

1. Informed consent

POLITÉCNICO
DE SANTARÉM
ESCOLA SUPERIOR
DE DESPORTO
DE RIO MAIOR

Instituto Politécnico de Santarém

Escola Superior de Desporto de Rio Maior

Exmº/ª. Sr.(ª)

A investigadora Nancy Brígida, sob orientação do Professor Doutor Marco Branco e do Professor Doutor David Catela irá elaborar um estudo de investigação do Mestrado em Atividade Física e Saúde da Escola Superior de Desporto de Rio Maior, intitulado "Níveis de Atividade Física e Complexidade da Motricidade Fina e Grossa em Diferentes Tarefas em Indivíduos com Fibromialgia".

A Fibromialgia afeta entre 2% a 4% da população, caracterizando-se por uma doença músculo-esquelética incapacitante com dor muscular crónica e generalizada, associada à fadiga, distúrbios do sono, défice cognitivo, défice de equilíbrio e controlo postural, baixa aptidão muscular e desempenho funcional. Este comprometimento funcional pode estar relacionado com a presença de distúrbios na função motora e falhas nos mecanismos de controlo motor central, afetando a qualidade de vida destes indivíduos, destacando a necessidade de uma abordagem de gestão personalizada e promovendo uma maior capacidade de adaptação e controlo motor. Com objetivo de avaliar o efeito da Atividade Física na coordenação motora desta população, pretendemos analisar a entropia através de métodos de análise não-linear, de forma a verificar a interação que existe entre: a severidade dos sinais e sintomas da doença, os níveis de atividade física e a entropia em exercícios de motricidade fina e grossa.

Este estudo requer a recolha de dados com sensores inerciais e vídeo (apenas gravação do movimento da mão) durante a realização do *Finger Tapping Test*, da marcha e do exercício de sentar e levantar (apenas com sensores inerciais). A recolha dos níveis de atividade física será realizada através da utilização de um relógio específico para esse efeito durante 7 dias. As recolhas de dados não implicam qualquer tipo de risco presente ou futuro para os participantes.

Na ficha de registo dos dados, não constará o nome dos participantes e a identificação de cada um será realizada através de uma letra e um número (por exemplo: S1). Como em qualquer investigação, o tratamento dos dados é confidencial e anónimo. Os dados só serão utilizados para publicações científicas e as identificações serão destruídas 3 anos após o término do estudo. Os resultados serão disponibilizados em formato de relatório e esclarecidos se solicitados. Se publicados, os dados só serão apresentados em valores estatísticos, por exemplo, média e com as identificações codificadas.

O participante rege-se no direito de desistir do estudo a qualquer momento, sem quaisquer consequências.

Deste modo, vimos solicitar a V.ª Ex.ª que se digne autorizar a referida investigadora a recolher e tratar os dados no âmbito deste estudo. A equipa de investigação está inteiramente à disposição de V.ª Ex.ª para quaisquer esclarecimentos adicionais.

Antecipadamente grata pela atenção dispensada,

Rio Maior, em ____ de _____ de _____ P'la Equipa de Investigação

Contactos: E-mail: nancybrigida@esdrm.ipsantarem.pt Telemóvel: 913059670

✂----------(Separar por aqui e ficar com Pedido de Consentimento Informado) ----------

Eu (nome) _____, li e compreendi as informações prestadas pelo que autorizo a minha recolha de dados e participação no estudo "Níveis de Atividade Física e Complexidade da Motricidade Fina e Grossa em Diferentes Tarefas em Indivíduos com Fibromialgia".

_____, ____/____/_____ _____

(Assinatura)

Inquérito Fibromialgia

A investigadora Nancy Brígida, sob orientação do Professor Doutor Marco Branco e do Professor Doutor David Catela irá elaborar um estudo de investigação do Mestrado em Atividade Física e Saúde da Escola Superior de Desporto de Rio Maior, intitulado "Níveis de Atividade Física e Complexidade da Motricidade Fina e Grossa em Diferentes Tarefas em Indivíduos com Fibromialgia". Este inquérito e questionário tencionam recolher informação útil para o desenvolvimento do estudo e avaliar o impacto da Fibromialgia nos participantes. A informação recolhida terá sempre como garantia a sua confidencialidade e em momento algum os dados serão transmitidos a terceiros. O conteúdo será recolhido de forma anónima.

Código do Sujeito:_____

Data de Nascimento:_____

Sexo: Masculino____ Feminino____

Altura:_____

Peso:_____

Mão Preferida:_____

Contacto:_____

Localidade:_____

Profissão:_____

Relatório de Diagnóstico de Fibromialgia: Sim_____ Não _____

Sinais e Sintomas mais Frequentes:

_____

_____

_____

Outros Diagnósticos:

_____

_____

Pratica Atividade Física Regularmente: Não_____ 1-2 x/sem_____ 2-3 x/sem_____ >3 x/sem_____

Tipo de Atividade Física:_____

2. Fibromyalgia survey

3. Fibromyalgia impact questionnaire

Fibromyalgia Impact Questionnaire - FIQ

Nas perguntas 1 a 11 por favor assinale o número que, em relação à última semana, melhor descreve a maneira como, em geral, foi capaz de executar as tarefas indicadas. Se habitualmente não faz um dessas tarefas não assinale nenhuma resposta à questão colocada.

Item 1

1. **Foi capaz de ir às compras?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

2. **Foi capaz de tratar da roupa na máquina de lavar/secar?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

3. **Foi capaz de cozinhar?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

4. **Foi capaz de lavar a louça à mão?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

5. **Foi capaz de aspirar a casa?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

6. **Foi capaz de fazer as camas?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

7. **Foi capaz de andar vários quarteirões (200 a 500 metros)?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

8. **Foi capaz de visitar a família ou os amigos?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

9. **Foi capaz de tratar das plantas ou praticar o seu passatempo?**

   Sempre ___0___ 1 ___ 2 ___3___ Nunca

10. **Foi capaz de se deslocar, no seu próprio carro ou em transportes públicos?**

    Sempre ___0___ 1 ___ 2 ___3___ Nunca

11. **Foi capaz de subir as escadas?**

    Sempre ___0___ 1 ___ 2 ___3___ Nunca

Item 2 – Na última semana, em quantos dias se sentiu bem?

___0___1___2___3___4___5___6___7___

Item 3 – Na última semana, quantos dias faltou ao trabalho e/ou não realizou as tarefas domésticas?

___0___1___2___3___4___5___6___7___

Nas perguntas que se seguem, assinale o número que melhor indica o modo, como, em geral, se sentiu na última semana.

Item 4 – Nos dias que trabalhou, quanto é que a sua doença – Fibromialgia – Interferiu no seu trabalho?

Trabalhei sem problemas	__0__1__2__3__4__5__6__7__8__9__10__	Tive grande dificuldade no trabalho

Item 5 – Que intensidade teve a sua dor?

Não tive dor	__0__1__2__3__4__5__6__7__8__9__10__	Tive dor muito intensa

Item 6 – Que cansaço sentiu?

Não senti cansaço	__0__1__2__3__4__5__6__7__8__9__10__	Tive dor muito intensa

Item 7 – Como se sentiu quando se levantava de manhã?

Acordei bem repousado(a)	__0__1__2__3__4__5__6__7__8__9__10__	Acordei muito cansado(a)

Item 8 – Que rigidez sentiu?

Não tive Rigidez __0__1__2__3__4__5__6__7__8__9__10__ Senti muita Rigidez

Item 9 – Sentiu-se nervoso(a) ou ansioso(a)?

Não tive Ansiedade __0__1__2__3__4__5__6__7__8__9__10__ Senti-me muito Ansioso(a)

Item 10 – Sentiu-se triste ou deprimido(a)?

Não me senti demrimido(a) __0__1__2__3__4__5__6__7__8__9__10__ Senti-me muito Deprimido(a)

4. Visual analog scale

ESCALA VISUAL ANALÓGICA

A Escala Visual Analógica consiste numa linha horizontal, ou vertical, com 10 centímetros de comprimento, que tem assinalada numa extremidade a classificação "Sem Dor" e, na outra, a classificação "Dor Máxima", entre outros.

O doente terá que colocar uma cruz, ou um traço perpendicular à linha, no ponto que representa a intensidade da sua Dor. Há, por isso, uma equivalência entre a intensidade da Dor e a posição assinalada na linha reta.

Mede-se, posteriormente e em centímetros, a distância entre o início da linha, que corresponde a zero e o local assinalado, obtendo-se, assim, uma classificação numérica que será assinalada na folha de registo.

Código do Sujeito _____

Escala de Dor

_____

Sem Dor Dor Máxima

Escala de Fadiga

_____

Sem Fadiga Fadiga Máxima

Data_____/_____/_____

_____

(Assinatura do Praticante)