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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Interoception and proprioception in fibromyalgia

Nienke Hellings
Cédric Philippe

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij neurologische aandoeningen

PROMOTOR :
Prof. dr. Katleen BOGAERTS

BEGELEIDER :
Mevrouw Indra RAMAKERS

UHASSELT
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www.uhasselt.be
Universiteit Hasselt
Campus Hasselt:
Martelarenlaan 42 | 3500 Hasselt
Campus Diepenbeek:
Agoralaan Gebouw D | 3590 Diepenbeek

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Research context

This master’s thesis forms an integral part of the Master in Rehabilitation Sciences and Physiotherapy of Hasselt University. This study is situated in the research field concerning somatically unexplained physical symptoms and remains relatively novel. Since there is still a lot left to discover regarding fibromyalgia (FM) and its underlying mechanisms, this research tries to clarify the role of proprioception and interoception within this condition. These factors have never been studied together in a research on FM. The aim of this research is thus to examine potential differences between healthy controls (HC) and FM patients in terms of proprioception and interoception. The investigation was conducted primarily by two students, namely Hellings Nienke and Philippe Cédric, both of whom are currently enrolled in the Rehabilitation Sciences and Physiotherapy program at Hasselt University. The study adheres to the central format, with the research question developed by the students themselves. The two students collaborated with fellow students from their research group to recruit participants and collect the requisite data. The recruitment of patients was facilitated by the assistance of Reumacenter (Genk, Belgium), ReumaClinic (Genk, Belgium), and Tumi Therapeutics (Heusden-Zolder, Belgium). The proprioception assessments were carried out at the laboratories of Hasselt University, while interoception assessments were done at ZOL Campus St. Barbara Lanaken. Independently, the two students assessed the data, conducted statistical analyses and completed the academic writing process. Supervision and guidance was provided by Professor Dr. K. Bogaerts and Dra. I. Ramakers, with the latter providing consistent feedback during the development of this master's thesis.

Acknowledgements

We extend our heartfelt gratitude to all individuals whose contributions made this project possible. First and foremost, we are grateful for the volunteers that have actively participated in our research. Their commitment and cooperation were crucial in our investigation. We are also thankful for the opportunity to recruit participants from Tumi Therapeutics (Heusden-Zolder), ReumaClinic (Genk), and Reumacenter (Genk). Furthermore, we would like to acknowledge our promotor Prof. Dr. Katleen Bogaerts for her expertise and insightful feedback. A special thanks to Dra. Indra Ramakers for her direct guidance, targeted feedback, and encouragement throughout the process of creating this master's thesis. We extend our appreciation to the University of Hasselt for generously providing the facilities and resources essential for the execution of our study. Finally, ZOL Campus St. Barbara Lanaken is appreciated for providing us access to their laboratory and advanced technology, which were instrumental in conducting our investigation.

Abstract

Background: Interoception and proprioception play crucial roles in motor control, pain perception and emotional processing. Dysfunctions in proprioceptive and interoceptive processes can possibly be implicated in the pathophysiology of fibromyalgia (FM).

Objective: The aim of this study was to investigate differences in interoception and proprioception between FM patients and healthy controls (HC).

Methods: The FM patients (*n*=26) and HC (*n*=26) underwent the Respiratory Occlusion Discrimination (ROD) task to measure interoceptive accuracy, the Three-Domain Interoceptive Sensations Questionnaire (THISQ) and Interoceptive Sensitivity and Attention Questionnaire (ISAQ) to measure interoceptive sensitivity. Proprioception was assessed using the Cervical Joint Position Error Test (CJPET) and Postural Control Task. The two-sample *t*-test and rank-sum test were used for statistical comparisons.

Results: FM patients exhibited significantly higher scores on the F3 subscale (p = .009) of the THISQ, but no differences were found on the F1 (p = .120) and F2 (p = .386) subscales. Furthermore, FM patients showed significantly higher scores on the F1 subscale of the ISAQ (p = .012). No significant differences were found in interoceptive accuracy (p = .139). Additionally, FM patients displayed significantly higher relative proprioceptive weighting (RPW) unstable ratios (p = .044) and mean reposition errors in the CJPET (p = .027; .019). The RPW ratios in the stable condition did not show any differences (p = .248).

Conclusion: FM patients are more sensitive to neutral body sensations compared with HC. Moreover, they also display greater reliance on ankle proprioception and cervical joint position errors.

Keywords: Fibromyalgia, Interoceptive accuracy, Interoceptive sensibility, Postural Control Task, Cervical Joint Position Error Test

Table of Contents

1 Introduction

Fibromyalgia (FM) is a chronic syndrome affecting 2-8% of the world population. The vast majority of the patients in this group are women (Siracusa et al., 2021). FM is classified as a functional somatic syndrome, meaning that it is defined by the presence of chronic symptoms that cannot be fully explained by a well-known organic disease (Donnachie et al., 2020; Mayou & Farmer, 2002).

The underlying mechanisms of FM are still unknown, but it is possible that interoception and proprioception are involved. Notably, Valenzuela-Moguillansky et al. (2017) shed light on the complex interplay between FM and their embodied experiences. This becomes more apparent when considering the concept of interoception, explained by Khalsa (2018), as “the process through which the nervous system comprehends and integrates signals arising from within the body providing a moment-by-moment mapping of the body's internal landscape across conscious and unconscious levels'' (p. 1). A mismatch in interoception, meaning conflicts in accurately understanding and processing internal signals can be an explanation for the generation and sustaining of symptoms seen in FM patients. Further emphasizing the concept of interoception, Garfinkel et al. (2015) delineate it into three distinct measurable constructs: (1) interoceptive accuracy (objective detection of internal physical feelings), for example detection of dyspnea through help of a rebreathing task (Bogaerts et al., 2008; Van Den Houte et al., 2018); (2) interoceptive sensibility (one’s beliefs and ability to focus on internal physical feelings), for example, how frequently a person reports to pay attention to their heart pounding (Vlemincx et al., 2021); and (3) interoceptive awareness (metacognitive awareness of interoceptive accuracy), for example, one's conscious perception of their heartbeat or breathing (Price & Hooven, 2018). The findings on interoceptive accuracy and interoceptive sensibility in FM patients are contradictory. While some studies have revealed no differences between FM patients and healthy controls (HC) in terms of interoceptive accuracy (Borg et al., 2018; Rost et al., 2017), others discovered that interoceptive sensibility was significantly higher in FM patients (Bogaerts et al., 2021; Schmitz et al., 2021).

Proprioceptive abnormalities have been documented in FM patients (Güçmen et al., 2022). Proprioception is the ability of a person to perceive its own body location in space (Moon et al., 2021). It can be measured via several submodalities, such as postural control and joint position sense (JPS) (Héroux et al., 2022; Myers et al., 2009). The ability to recognize a given joint angle and then actively or passively replicate the same joint angle after moving a limb is known as JPS

(Riemann & Lephart, 2002). Postural control is characterized as the action of preserving, attaining, or reinstating a state of balance throughout various postures or activities (Pollock et al., 2000). Cervical JPS (the sense of the neck and head position in space) and postural control are closely tied to each other (Reddy et al., 2022).

Limited research exists on proprioception in FM. Studies show that FM patients exhibit higher cervical JPS error scores and diminished postural control compared to HC (Güçmen et al., 2022; Reddy et al., 2022). Additionally, Toprak Çelenay et al. (2019) found that women with FM experience postural instability and poor trunk position sense compared to HC. While studies on knee (Ulus et al., 2013), upper limb (Brun et al., 2020), and shoulder (Bardal et al., 2016) proprioception in FM patients exist, no significant differences were observed compared to HC. JPS is the only component of proprioception that is utilized to establish proprioceptive accuracy, according to the first review on proprioception in FM patients. Furthermore, there are numerous techniques to quantify proprioception, but only one approach has been used on a restricted number of body areas in this population. These results point to important gaps in the existing literature that require more research (Ramakers, 2024).

Building upon the existing literature this study aims to investigate if there is a difference in interoception and proprioception when comparing FM patients with HC. Consistent with the observations in existing literature, we hypothesize that FM patients will demonstrate heightened neutral interoceptive sensibility (Bogaerts et al., 2021). We hypothesize that interoceptive accuracy will not differ between FM patients and HC in a neutral affective context (Bogaerts et al., 2008; Borg et al., 2018; Rost et al., 2017). Proprioception during postural control has never been studied before in patients with FM. Given that FM is characterized by chronic pain, it is hypothesized that individuals with FM may exhibit postural control deficits similar to those observed in individuals with NSLBP. Specifically, we expect that they will depend more on ankle proprioception in both stable and unstable settings and have larger relative proprioceptive weighting (RPW) ratios than HC in both scenarios (Claeys et al., 2010). We hypothesize to discover higher errors in the cervical JPS of the FM group compared to HC (Güçmen et al., 2022; Reddy et al., 2022). Findings may pave the way for future research aimed at developing targeted interventions to improve interoception and proprioception in FM patients, ultimately leading to enhanced symptom management.

2 Methods

2.1 Participants

2.1.1 Patient group

FM patients (*n* = 26) were recruited from Reumacenter (Genk, Belgium), ReumaClinic (Genk, Belgium), Tumi Therapeutics (Heusden-Zolder, Belgium), but also through closed Facebook groups and local advertisements. The American College of Rheumatology (ACR) criteria for FM were used for inclusion (Wolfe et al., 2016). The exclusion criteria were: (1) pregnancy, (2) being younger than 18 years old and older than 65 years old, (3) DSM-V-diagnosed depressive episode, anxiety disorder, eating disorder, substance abuse, psychotic disorder, or neurocognitive disorder (assessed by the MINI-s; Overbeek et al., 1999), (4) presence of a chronic organic disorder (present for at least 3 months, e.g., asthma, diabetes) or acute organic disorder (e.g., the flu, fever), (5) neck complaints at the moment of assessment (not related to the current problem), (6) recent whiplash trauma, less than 3 months ago or longer than 3 months ago with persistent complaints, (7) diagnosis of organically explained vestibular or neurological diseases, (8) recent orthopedic problems of the lower limbs that could influence balance (e.g., acute ankle trauma) and (9) BMI above 30. An informed consent was signed before any data was acquired and every participant was given a unique code in order to maintain their privacy.

2.1.2 HC group

HC (*n* = 26) were recruited via local advertisements and flyering. They were enlisted through frequency sampling and were only eligible to take part if an adequate number of FM patients within the corresponding age range (±5 years), BMI (±3), and the same gender category had already participated. For inclusion, a score of 75 or lower is required using the Checklist for symptoms in Daily life (CSD; Walentynowicz et al., 2018) questionnaire. The exclusion criteria in this group were: (1) pregnancy, (2) being younger than 18 years old and older than 65 years old, (3) DSM-V-diagnosed depressive episode, anxiety disorder, eating disorder, substance abuse, psychotic disorder, or neurocognitive disorder (assessed by the MINI-s; Overbeek et al., 1999), (4) presence of a chronic organic disease (present for at least 3 months, e.g., asthma, diabetes) or acute organic disorder (e.g., the flu, fever), (5) the presence of persistent physical symptoms, (6) neck complaints at the moment of assessment (not related to the current problem), (7) recent whiplash trauma less than 3 months ago or longer than 3 months ago with persistent complaints,

(8) diagnosis of organically declared vestibular or neurological diseases, (9) recent orthopedic problems of the lower limbs that could influence balance and (e.g., ankle trauma) and (10) BMI above 30. Prior to any data acquisition, the informed consent was signed in person and to ensure anonymity, a unique code was assigned to every one of them.

This research was approved by the Committee for Medical Ethics of Hasselt University on 04/05/2022 (Approval Number: B1152022000007).

2.2 Materials and procedure

2.2.1 Interoception

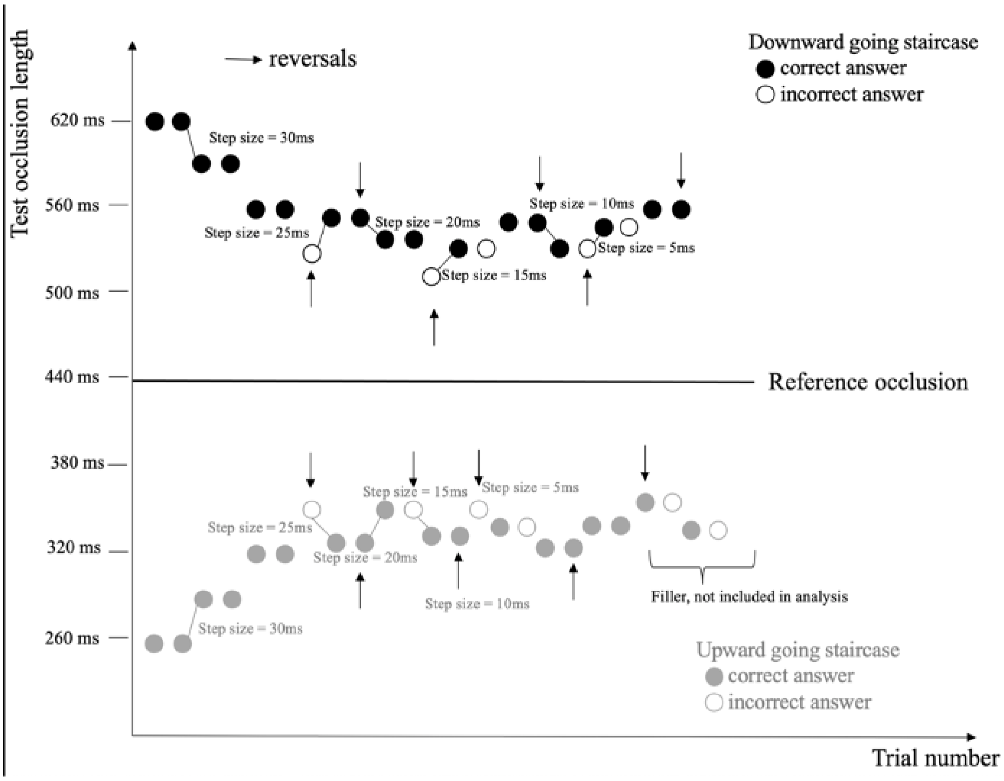
2.2.1.1 Interoceptive accuracy

The Respiratory Occlusion Discrimination (ROD) task was used to measure interoceptive accuracy in a neutral context. This task was introduced and validated in a healthy population by Van Den Houte et al. (2018). The task consists of a breathing exercise, in which the participants must breathe at a normal pace through a mouthpiece with a nose clip, while experiencing respiratory occlusions (short inspirational stops). The occlusions are neither painful nor uncomfortable. Required materials for this task are the Hans Rudolph Pneumotach Amplifier 1 (Series 1110, Hans Rudolph Inc., Shawnee, USA) and an automated pneumatic inflatable balloon-type valve controller (8230AF Series; Hans Rudolph Inc., Shawnee, USA).
One trial consists of two inspiratory occlusions carried out in a random order, one of which is the reference occlusion, 440 ms, and the other is the test occlusion which is either shorter or longer than 440 ms. The aim for the participants is to distinguish the differences in length of the occlusions. The lengths of the occlusions vary between 260 ms and 620 ms. 300 ms make up the inter-occlusion interval. The just noticeable difference (JND) in lengths of inspiratory occlusions was then determined by the adaptive staircase paradigm.
Typically, staircase methods are created so that as the staircase gets longer (and the difference in stimulus intensity gets lower over time), it gets harder to distinguish between the two stimuli. The two-down, one-up approach is utilized in this experiment, requiring participants to provide two consecutively accurate responses to reduce the difference between the test and reference stimulus, but only one incorrect response is needed to increase the difference between the two stimuli. With this method, the 70.7% correct differentiation point of the psychometric function is estimated. An upward stage (where test occlusions are shorter than the reference occlusion) and a

downward stage (where test occlusion lengths are greater than those of the reference occlusion) will both be present in one block of the experiment (see Figure 1).

The trials begin with a 30 ms step size. With each reversal (change in stage direction), the step size is decreased by five ms, until the minimal step size of five ms is reached. When both stages have experienced six reversals, the experiment is complete. For figures, see Appendix A.

Figure 1



Sample Block from the Task for Respiratory Accuracy

Note. Trial N belongs to the upward stage, trial N + 1 to the downward stage, trial N + 2 to the upward stage, and so on. The two stages are presented interchangeably.

Retrieved from “The respiratory occlusion discrimination task: A new paradigm to measure respiratory interoceptive accuracy”, by Van Den Houte et al., 2021, *Psychophysiology, 58*(4) (https://doi.org/10.1111/psyp.13760).

2.2.1.2 Interoceptive sensibility

Interoceptive sensibility was examined using the Three-domain Interoceptive Sensations Questionnaire (THISQ; Vlemincx et al., 2021) and Interoceptive Sensitivity and Attention Questionnaire (ISAQ; Bogaerts et al., 2021).

2.2.1.2.1 Three-domain Interoceptive Sensations Questionnaire (THISQ)

The THISQ, comprising 18 items, demonstrates good validity and reliability as indicated by Vlemincx et al. (2021). The questionnaire has three subscales: (F1) cardiorespiratory activation, (F2) cardiorespiratory deactivation, (F3) gastroesophageal sensations. Convergent, divergent validity and high test-retest reliability were proven. Cronbach's alphas of total THISQ scores were showed acceptable to good internal consistency (Vlemincx et al., 2021). The questionnaire aims to investigate how people perceive neutral body sensations that come from three different physiological systems: the respiratory, gastroesophageal and cardiac systems. The elements related to various levels of physical activity involve both activation and deactivation of the respiratory and cardiac domains. The gastroesophageal elements included sensations from movement and contractions in the esophagus, stomach, and colon. Participants rated how often each phrase related to them in their daily lives on a 5-point Likert scale ranging from 1 ('never') to 5 ('always') (Vlemincx et al., 2021).

2.2.1.2.2 Interoceptive Sensitivity and Attention Questionnaire (ISAQ)

The ISAQ consists of 17 statements covering a wide variety of modalities (cardiovascular, respiratory, gastrointestinal, cerebral, energy level, posture with related muscles, and thermoregulation). Reliability and validity of this questionnaire were also confirmed. The questionnaire has three subscales: (F1) sensitivity to neutral body sensations, (F2) attention to unpleasant body sensations, and (F3) difficulty disengaging from unpleasant body sensations. The only subscale that will be used to investigate interoceptive sensibility in this study is F1, as F2 measures interoceptive attention and F3 is considered invalid (Bogaerts et al., 2021). The scale's convergent and divergent validity were confirmed. High test-retest reliability was proven. The Cronbach alpha of the first subscale (F1) was showing acceptable internal consistency (Bogaerts et al., 2021). The 5-point Likert scale, ranging from 1 ('strongly disagree') to 5 ('strongly agree') was used to score the items.

2.2.2 Proprioception

2.2.2.1 Cervical joint position error test (CJPET)

This golden standard test was introduced by Revel et al. (1991). It is reported to have sufficient reliability and validity (AlDahas et al., 2024). The participants were positioned 90 centimeters from the wall on a chair with back support. They had to put on a headlamp and blinded glasses. The eyes were to remain closed throughout the experiment. A white piece of paper was hung on the wall and the starting, neutral head position was visualized by a light dot. The participants had to actively turn their head maximally to the right and then return to the starting position, this position was then indicated on the paper. This was performed five times to the right and to the left. After each attempt, a manual correction of the head was made by the researcher indicating the true initial position. For figures, see Appendix B.

2.2.2.2 Postural Control Task

The Postural Control Task used in this study was established by Brumagne et al. (2008). Following the introduction of the task and prior to the start, the feet needed to be measured. A line was drawn at the center of the foot, so that it would line up with the center of the force plate. The force plate was covered with a transparent foil, upon which the outline of the feet was drawn with the forefoot spread, according to the participant's preference, and the heels spaced ten centimeters apart. The purpose of this was to enable the participants to stay in the same spot on the force plate at all times. For this assessment, the lower back, calves and feet were exposed.
To appraise proprioception during postural control, two test conditions were used: (1) an upright standing position on a stable support surface, the plate and (2) an upright standing position on an unstable support surface or foam. Shakers (self-manufactured with Maxon motors, Switzerland) that cause a muscle vibration were counterbalanced over the triceps surae, ankle muscles and at the level of the lumbar paraspinal, back muscles (Goossens et al., 2019). These muscles resemble the muscles utilized in an ankle-steered strategy or a multi-segmental technique, according to Brumagne et al. (2008). The vibration of the shakers generates a sensation of elongation which requires the participants to correct with their center of pressure (CoP) in the opposite direction. The vision was obstructed with blinded glasses, but participants had to keep their eyes open. The participants were told to stand up straight and remain as relaxed, but immobile as possible for the duration of each experiment.
Each test lasted one minute and was constructed the same. During the first 20 seconds of the experiment, the participant had to stand still. After approximately 20 seconds the shakers would

vibrate for 15 seconds. Once the shakers were turned off the participants had to remain motionless for another 30 seconds. At all times, an investigator kept a close observation on the safety of the participant. For figures, see Appendix C.

2.3 Data analysis

Group differences were calculated using the software program JMP Pro 17.0.0 (SAS Institute USA). The differences between the FM and HC groups were analyzed with a significance level of $p = .05$. Based on the decision trees outlined in Appendix D, the relevant statistical tests were selected. The two-sample *t*-test was used when the assumption of normality was met and variances were equal. When the assumption of normality was not met for one of the groups, the non-parametric Wilcoxon rank-sum test was used to differentiate between the FM and HC groups. Effect sizes were calculated using Cohen's *d*. The ROD task was used to measure interoceptive accuracy, performance was determined by calculating the JND, which is the average difference between the test and reference lengths in trials where reversals occur. The THISQ and ISAQ subscale scores were used to measure interoceptive sensibility. To quantify the cervical proprioceptive accuracy, the margin of error (the distance in centimeters between the marked spots and the designated beginning point) was used to evaluate the mean reposition error (Revel et al., 1991). The optimal method for assessing the postural reaction to muscle vibration has been identified as the RPW, computed as: RPW = |ankle| / (|ankle| + |back|), where |ankle| and |back| represents the absolute values of mean CoP displacement before, after and during the vibrations. A RPW score of 1 signifies 100% proprioceptive reliance on the ankle muscles, while a score of 0 indicates 100% dependence on the back muscles (Goossens et al., 2019).

3 Results

3.1 Sample characteristics

A power analysis using G*Power software was conducted to determine the sample size of 26 participants in each group. The demographic characteristics of the participants (N = 52), presented in Table 1, did not significantly differ (p > .05) between the FM group (n = 26) and HC group (n = 26).

Table 1

Demographic characteristics of the participants for FM and HC

Group	FM (n = 26; 96% female)			HC (n = 26; 96 % female)		
	M	*SD*	Range	*M*	*SD*	Range
Age (years)	48.00	9.28	29.00-61.00	43.00	12.96	22.00-60.00
BMI (kg/m²)	24.60	4.50	17.40-31.20	23.65	2.86	19.00-29.80

Notes. FM = Fibromyalgia; HC = Healthy controls; BMI = Body mass index

3.2 Outcomes

3.2.1 Interoceptive sensibility

Group differences in the scores of the THISQ and ISAQ subscales between FM and HC are presented in Table 2. Group differences of the ISAQ F1 subscale without the outlier in the FM patient group are presented in Table 3. For the subscales of the THISQ, a two-sample t-test was performed, revealing statistically significantly higher scores in the FM group compared to the HC group (F = 6.10, p = .009) for the third subscale of the THISQ, the gastroesophageal sensations (F3). A Cohen's d of .70 indicates a moderate effect size for this significant result. No statistically significant differences were observed for the cardiorespiratory activation (F1) (F = 1.41, p = .120) and cardiorespiratory deactivation (F2) (F = .09, p = .386) subscales. For the subscale of the ISAQ, a two-sample t-test was performed revealing statistically significantly higher scores in the FM group without the outlier compared to the HC group for the sensitivity to neutral body sensations (F1) (F

= 5.42, *p* = .012) subscale. A Cohen's *d* of .03 indicates that the significant result demonstrates a very small effect size. The reason for the exclusion of the outlier was their remarkably low score on this subscale compared to the other FM patients. No statistically significant differences were found for the sensitivity to neutral body sensations (F1) (*F* = 1.92, *p* = .086) subscale with the inclusion of the outlier (see Figure 2, 3, 4, 5).

Table 2

Interoceptive Sensibility Means and Standard Deviations for FM and HC with Outlier

Group	FM (n = 26)		HC (n = 24)					
	M	*SD*	*M*	*SD*	*df*	*F*	*p*	Cohen's *d*
THISQ F1	21.58	3.87	20.25	4.02	48	1.41	.120	.34
THISQ F2	19.38	4.86	19.79	4.70	48	.086	.385	.09
THISQ F3	17.50	5.02	14.04	4.87	48	6.09	.009**	.70
ISAQ F1	32.85	5.76	30.96	3.50	48	1.92	.086	.40

Notes. FM = Fibromyalgia; HC = Healthy controls; THISQ = Three-domain Interoceptive Sensations Questionnaire; THISQ F1 = cardiorespiratory activation; THISQ F2 = cardiorespiratory deactivation; THISQ F3 = gastroesophageal sensations; ISAQ = Interoceptive Sensitivity and Attention Questionnaire; ISAQ F1 = sensitivity to neutral body sensation.

**p < .01

Table 3

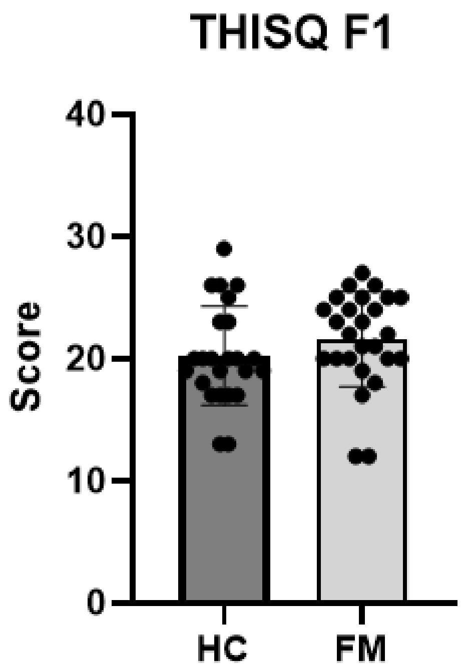
Interoceptive Sensibility Means and Standard Deviations for FM and HC without Outlier

Group	FM (n = 25)		HC (n = 24)					
	M	*SD*	*M*	*SD*	*df*	*F*	*p*	Cohen's *d*
ISAQ F1	33.60	4.38	30.96	3.50	47	5.42	.012*	.03

Notes. FM = Fibromyalgia; HC = Healthy controls; ISAQ = Interoceptive Sensitivity and Attention Questionnaire; ISAQ F1 = sensitivity to neutral body sensation.

*p < .05

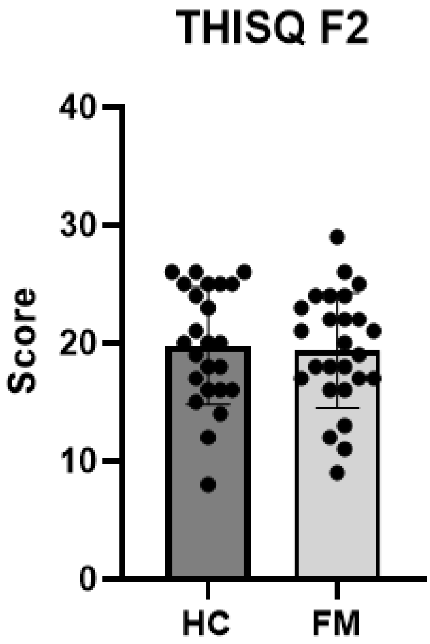
Figure 2



Individual Values of THISQ F1 Score with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; THISQ F1 = cardiorespiratory activation.

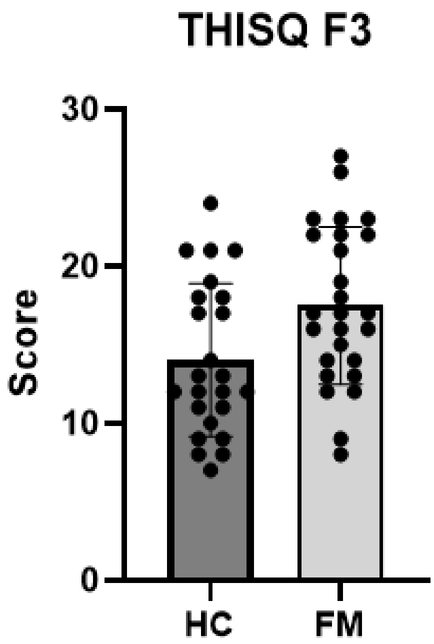
Figure 3



Individual Values of THISQ F2 Score with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; THISQ F2 = cardiorespiratory deactivation.

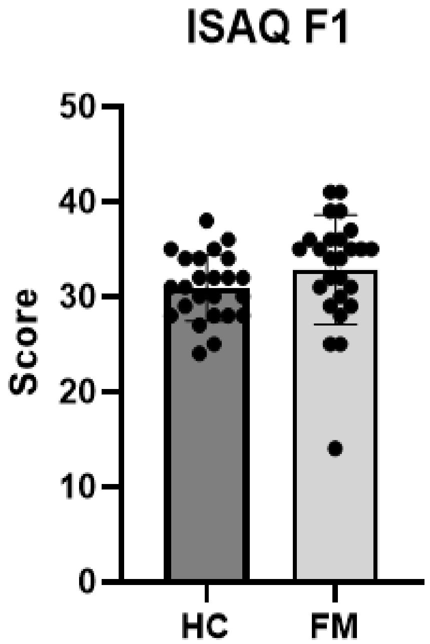
Figure 4



Individual Values of THISQ F3 Score with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; THISQ F3 = gastroesophageal sensations.

Figure 5



Individual Values of ISAQ F1 Score with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; ISAQ F1 = sensitivity to neutral body sensation.

3.2.2 Interoceptive accuracy

Group differences in the JND scores between FM and HC are presented in Table 4. Using a two-sample *t*-test (F = 2.26, p = .139), no statistically significant difference was found (see Figure 6).

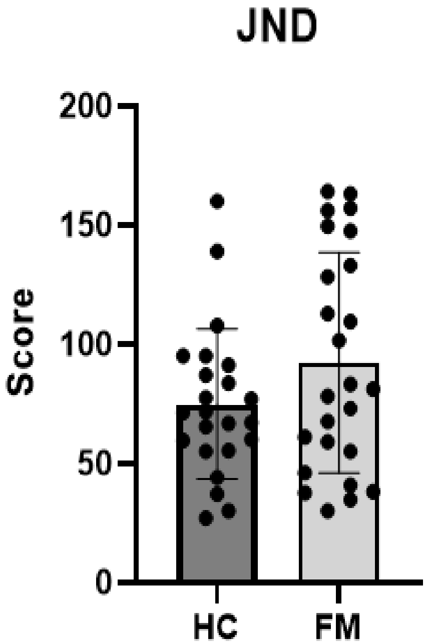
Table 4

Interoceptive Accuracy Means and Standard Deviations for FM and HC

Group	FM (n = 25)		HC (n = 23)					
	M	*SD*	*M*	*SD*	*df*	*F*	*p*	Cohen's *d*
JND	92.32	46.28	74.90	31.58	46	2.26	.139	.43

Notes. FM = Fibromyalgia; HC = Healthy controls; JND = Just noticeable difference.

Figure 6



Individual Values of JND with Mean and Standard Deviation of HC group and FM group

Notes. FM = Fibromyalgia; HC = Healthy controls; JND = just noticeable difference.

3.2.3 Postural Control Task

Group differences of the RPW stable and unstable ratio between the FM and HC group are presented in Table 5. For the RPW unstable ratio, the non-parametric Wilcoxon rank-sum test was performed, showing a statistically significantly higher score in the FM group compared to the HC group (F = 2.66, p = .044). A Cohen's *d* of .46 indicates that the significant result demonstrates a small effect size. For the RPW stable ratio, a two-sample *t*-test was performed, showing no statistically significant difference (F = 0.47, p = .248) (see Figure 7 and 8).

Table 5

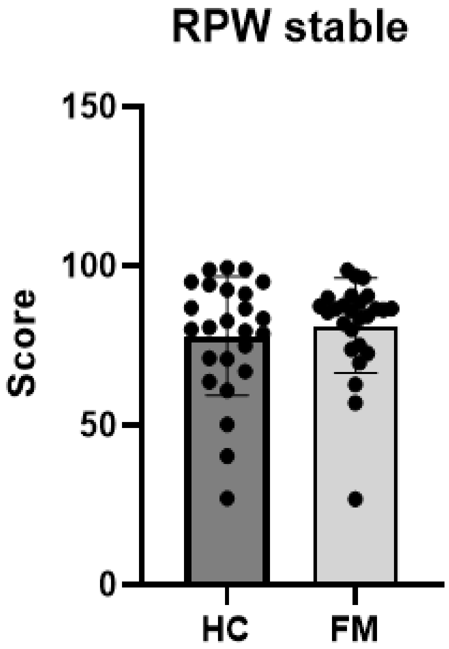
Postural Control Task Means and Standard Deviations for FM and HC

Group	FM (n = 26)		HC (n = 25)					
	M	*SD*	*M*	*SD*	*df*	*F*	*p*	Cohen's *d*
RPW Stable	81.16	14.87	77.94	18.57	49	.47	.248	.19
RPW Unstable	60.32	22.70	51.25	16.04	48	2.66	.044*	.46

Notes. FM = Fibromyalgia; HC = Healthy controls; RPW = Relative proprioceptive weighting ratio.

*p < .05

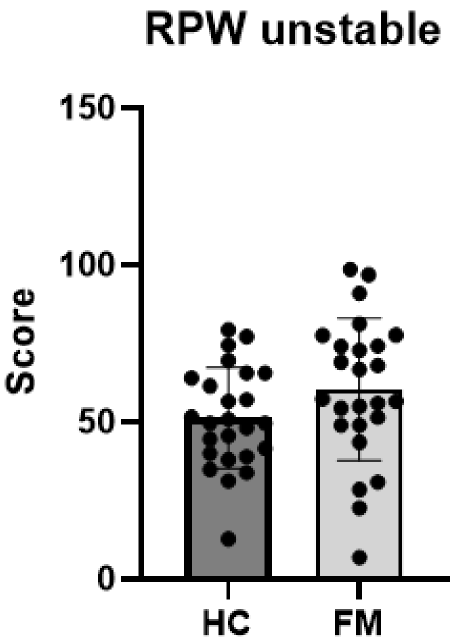
Figure 7



Individual Values of RPW Stable Ratio with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; RPW= relative proprioceptive weighting.

Figure 8



Individual Values of RPW Unstable Ratio with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; RPW= relative proprioceptive weighting.

3.2.4 Cervical Joint Position Error Test (CJPET)

Group differences between FM and HC for the CJPET of the left and right side are presented in Table 6. For both sides, a two-sample *t*-test was performed. The right side (F = 3.88, p = .027), as well as the left side (F = 4.52, p = .019), showed statistically significantly higher mean reposition errors in the FM group compared with the HC group (see Figure 9 and 10). A Cohen's *d* of .55 for the right side and .59 for the left side indicates that the significant results demonstrate moderate effect sizes.

Table 6

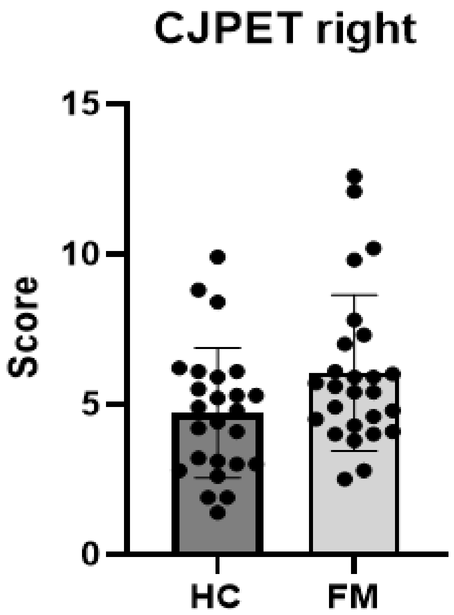
Cervical Joint Position Error Test (CJPET) Means and Standard Deviations for FM and HC

Group	FM (n = 26)		HC (n = 25)					
	M	*SD*	*M*	*SD*	*df*	*F*	*p*	Cohen's *d*
CJPET Right	6.04	2.60	4.72	2.17	49	3.88	.027*	.55
CJPET Left	5.69	2.71	4.28	1.98	49	4.52	.019*	.59

Notes. FM = Fibromyalgia; HC = Healthy controls.

*p < .05

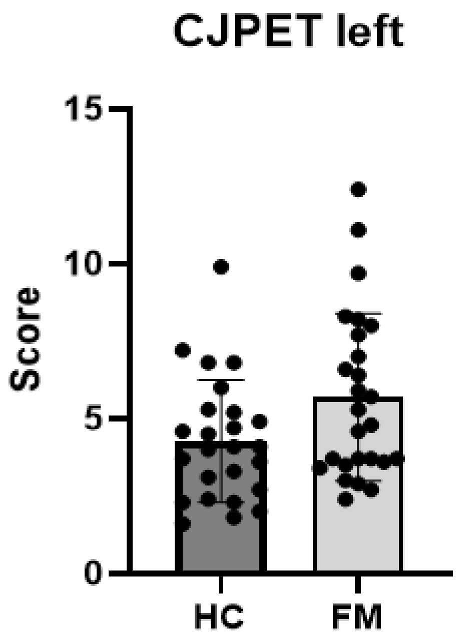
Figure 9



Individual Values of CJPET Right Score with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; CJPET = Cervical joint position error test.

Figure 10



Individual Values of CJPET Left score with Mean and Standard Deviation of HC Group and FM Group

Notes. FM = Fibromyalgia; HC = Healthy controls; CJPET = Cervical joint position error test.

4 Discussion

The aim of this study was to investigate potential differences in interoception and proprioception between FM patients and HC. The subjects of investigation for interoception were interoceptive sensibility and accuracy. For these topics, the ROD task, THISQ and ISAQ were the research tools. Proprioception was investigated during the Postural Control Task and the CJPET was used for the examination of cervical proprioception.

The findings support the proposed hypothesis that FM patients will demonstrate heightened interoceptive sensibility in a neutral affective context. More specifically, FM patients score significantly higher on the THISQ F3 subscale, indicating that statements pertaining to the gastroesophageal items (neutral sensations from esophageal, stomach and colon movements or contractions) applied a lot to them in their daily life compared to the HC group (Vlemincx et al., 2021). No significant differences were observed in the remaining subscales of the THISQ. There are currently no comparative studies because the THISQ has never been employed in a patient sample before. Excluding the outlier for the results of the ISAQ leads to similar results as the study of Bogaerts et al. (2021), where FM patients had significantly higher scores on the F1 subscale (sensitivity to neutral body sensations) compared to HC.

According to the existing literature, the assessment of interoceptive accuracy is primarily based on measures of cardiac interoception, such as the heartbeat counting task (Santos et al., 2022). Recent research has demonstrated the reliability and validity of respiratory interoception using the ROD task (Van Den Houte et al., 2021). Our results of the ROD task show no significant differences between FM patients and HC. This demonstrates that FM patients did not face greater difficulty in accurately indicating internal signals during the ROD task in a neutral context, which aligns with the findings of Borg et al. (2018) and Rost et al. (2017). One explanation, previously cited by Rost et al. (2017) is that hypervigilance may be something dynamic and is activated especially in situations of pain and threat. For FM patients, breathing is not inherently threatening or unpleasant and the experimental environment did not imply a physiological threat, which possibly accounts for the absence of group differences. Bogaerts et al. (2021) reached a similar conclusion; internal sensations in people with functional somatic syndromes, such as FM, only become associated with a negative affective value when connected to threats to one's physical well-being. Increased trait negativity is then frequently linked to overreporting of symptoms in people. Studies carried out on these patient populations show that affective-motivational, rather than sensory-perceptual components of interoceptive feeling have a greater influence on symptom reporting (Bogaerts et al., 2008). This could possibly account for the absence of group differences in this study.

Moving on to proprioception, the hypothesis we formed based on the research of Güçmen et al. (2022) and Reddy et al. (2022) regarding the CJPET was confirmed. The FM patients exhibited significantly higher mean reposition errors compared to HC. These results imply that cervical proprioception is impaired in FM patients. Cervical proprioception in FM patients may deteriorate for a variety of reasons. Previous research by Peng et al. (2021) has demonstrated that proprioceptive problems can be triggered by muscle pain and fatigue.

Following are the results of proprioception during the Postural Control Task. Claeys et al. (2011) conducted a study examining postural control in individuals with NSLBP, a concern also reported by some of our FM patients. Based on their findings, we expect higher RPW ratios on both stable and unstable surfaces within FM patients compared to HC. FM patients showed higher RPW ratios when standing on an unstable surface, but not on a stable surface. This means that the FM group is more prone to rely on an ankle-steered strategy when standing on an unstable surface compared to HC. When standing on a stable surface, they were also able to rely on the proprioceptive input of the back muscles, but were still more reliant on ankle proprioception. A viable explanation for the higher reliance on ankle proprioception when standing on an unstable surface is a different muscle spindle density in the paraspinal muscles. This may contribute to possible alterations in proprioceptive feedback mechanisms altering their strategies for maintaining postural stability, with an increased reliance on ankle proprioception when maintaining balance on an unstable surface. Additionally, the link between muscle spindle density and oxidative capacity indicates a complex interplay between muscle physiology and motor control. This finding suggests that individuals with NSLBP may have a higher proportion of fatigable muscle fibers due to diminished oxidative capacity, potentially impacting their ability to regulate muscle activity and preserve balance during physical tasks. The unstable condition is also a more complex task that may cause difficulties with postural control, as cited in the study by Brumagne et al. (2008).

4.1 Limitations

It is important to discuss some relevant limitations. We must acknowledge that the majority of the participants in our sample are women. While FM is more prevalent among women, this does not preclude its occurrence in men. In order to achieve a more comprehensive understanding of the condition, future research should aim to include a more diverse sample. Another limitation is that, given the observational methodology employed in this study, causal relationships cannot be inferred. Consequently, the directional association between FM and diminished proprioception and interoception remains undetermined. This implies that it is impossible to determine whether patients developed proprioceptive or interoceptive problems as a consequence of FM, or if FM arose as a result of preexisting proprioceptive or interoceptive dysfunctions.

The CJPET measurements were done manually, this may also have created a margin of error compared to other studies where it is measured instrumentally. The cervical proprioception design is an active design, wherein participants have to turn their heads away and back to the neutral position, predetermined target position. Doing this five times to the right and left makes fatigue a factor that may have affected the results. Pain can also have an impact on the outcomes as FM patients experience chronic widespread pain. This may negatively affect their performance during testing (Bazzichi et al., 2020). There may also be an influence of memory problems in FM patients. Participants had to constantly recall their initial cervical position. However, as evidenced by the study of Castel et al. (2021), and Glass and Park (2001), FM patients may experience cognitive dysfunctions, including trouble sustaining attention and other memory problems making this a difficult test. Reddy et al. (2022) found the same significant cervical proprioceptive impairments in FM patients after performing the test only three times in each direction, possibly decreasing the influence of fatigue and memory problems. There may be a learning effect because the cervical proprioception test is carried out five times in a row, to the left and to the right with the examiner passively correcting the subject to the original starting position each time.

The day-to-day fluctuations in (musculoskeletal) complaints experienced by patients also impacts performance during testing, resulting in variability in the results. It is crucial that future studies develop strategies to reduce its influence.

4.2 Strengths

The most important strength of this study is its innovative design, marking a significant advancement in the field. The study represents the first attempt to evaluate proprioception and interoception simultaneously in individuals with FM while comparing with HC. The findings provide novel insights into the interactions between these modalities in this population. Furthermore, methodologies that have not previously been explored within the field of FM research are introduced here. In particular, the implementation of the ROD task and THISQ to assess interoception have never been undertaken in FM. These research methods will contribute to a more comprehensive understanding of the perceptions of their internal bodily sensations. Moreover regarding the THISQ and ISAQ F1 subscale, a high number of symptom items in interoception questionnaires may distort an assessment of overall self-reported interoception, its relationship with symptom perception processes and its role in health and disease. These questionnaires prevent biasing the overall assessment of interoception by its association with symptoms and the disease itself through the use of neutral internal sensations for questioning, as opposed to symptom-based questioning aims (Vlemincx et al., 2021). The Postural Control Task, which was employed to assess proprioception in FM patients for the first time, additionally provides unique insights into the motor control and balance challenges experienced by FM patients. These results will consequently facilitate the expansion of FM research and lead to a better comprehension of this complex condition.

In addition, the following strengths have been identified. The inclusion and exclusion criteria were carefully selected to recruit participants. This has a positive impact on controlling variables that might confound results. It provides homogeneity of the sample and generalizability of the results. The fact that this study met the predetermined participant count threshold established via power analysis is another advantage. Additionally, the identical group size in the FM and HC group, which could lead to more statistically significant differences. We employed a standardized protocol for providing instructions during the assessment sessions. This minimizes variations in execution, thereby enhancing interrater reliability and accuracy. The carry-over effect is minimized during the Postural Control Task due to the alternation of the lumbar and ankle vibrations. Because we used validated scales and tests, this research is certain to have acceptable validity, reliability, and cross-study comparability. These resources elevate the quality of the research findings, reduce measurement errors and make results easier to interpret.

4.3 Implications and recommendations for future research

This is the first study to investigate interoception and proprioception simultaneously in FM. As the roles of interoception and proprioception in FM are not yet fully understood, our findings may have implications for future research and rehabilitation. Diagnosing FM can potentially be facilitated by a deeper comprehension of these sensory systems. This could aid in the discovery of clinical patterns that set FM apart from other conditions that have similar symptoms. In the current study, there were no significant differences in interoceptive accuracy between FM patients and HC measured with the ROD task in a neutral context. This interoceptive task requires more research and could possibly yield different findings by adding a negative affect that creates a sense of threat or pain when performing the breathing task as indicated by Bogaerts et al. (2008). The third modality of interoception, interoceptive awareness was not investigated in this study, but may possibly play a role in FM as shown in the article of Duschek et al. (2015). This should be included in further research.

During the literature search on the CJPET, we could not find any passive reproduction designs of this task. Studies that include this type of design could be interesting to exclude possible confounders, such as fatigue.

Van Wesemael et al. (2024) conducted a systematic review and meta-analysis in low back pain patients investigating the link between pain-related fear, pain catastrophizing, and CoP displacement. Since pain-related fear and pain catastrophizing are also implicated in FM (Edwards et al., 2006; Hsiao et al., 2020; Meulders et al., 2015), future research should examine postural control tasks that are more challenging (in terms of sensorimotor demands) and/or threat-inducing (in terms of perceived risk or danger) as these may have a greater impact on the relationship between psychological variables associated with pain and CoP characteristics in FM patients.

Fall frequency is increased in FM due to significant impairments in postural control and cervical JPS (Reddy et al., 2022). This raises the demand for cervical proprioceptive analysis in clinical practice within this patient population, as the rehabilitation of cervical proprioception positively impacts postural control (Reddy et al., 2022). A possible explanation for this is a disruption of the somatosensory system. However, research about this is limited (Reddy et al., 2022). The significantly greater CoP displacement within the Base of Support during the Postural Control Task in FM patients may also be explained by postural anxiety and fear of falling. This has to be considered and investigated in further studies (Brumagne et al., 2008).

It is still unclear whether these differences in proprioceptive postural control are due to distinct peripheral inputs at the muscle spindle level, distinct sensory processing, or a combination of both, despite the specific evaluation of the proprioceptive system using muscle vibration. Future studies that combine brain imaging (e.g. fMRI, NIRS) with muscle vibration during postural control tasks could clarify this (Claeys et al., 2015).

A three-dimensional motion analysis system might be more appropriate than the force plate used in this research, as it provides more extensive information on the spatial orientation and dynamics of all body segments. Furthermore, electromyographic recordings of both trunk and lower limb musculature could demonstrate potential for improving our understanding of the complicated systems that govern postural control (Brumagne et al., 2008; Van Wesemael et al., 2024).

Research on proprioception may contribute to the development of new treatment strategies for FM. Improving proprioceptive processes could potentially form an indication for physical therapy, for example training postural control when perturbing the ankle-strategy. The implementation of exercises across a range of surfaces, including those of a stable and unstable nature, as well as those performed in varying postural positions, might improve proprioceptive abnormalities in these patients (Claeys et al., 2011). Sensory rehabilitation programs or neuromodulation techniques are therefore examples of treatments they could benefit from.
There is still a lot of research necessary for interoception, such as regarding the influence of affect on sensibility and accuracy, before we can consider potential rehabilitation strategies.

In general, more longitudinal studies are needed to deepen our understanding of the influence of interoception and proprioception in FM.

5 Conclusion

The aim of this study was to investigate differences in proprioception and interoception between FM patients and HC. Our research revealed significant differences between FM patients and HC in interoceptive sensibility. Moreover, FM patients exhibit a significantly higher score on the gastroesophageal sensations subscale of the THISQ and the sensitivity to neutral body sensations subscale of the ISAQ.

In terms of proprioception during the Postural Control Task, FM patients demonstrate significantly higher RPW ratios in the unstable condition compared to HC. This is indicative of an increased reliance on ankle proprioception during postural control. Furthermore, the cervical joint position errors were significantly higher in FM patients on both the left and right side compared to the HC. This shows impaired proprioceptive accuracy in FM. Interoceptive accuracy and the stable condition of the Postural Control Task did not exhibit significant differences between the two groups. Therefore, there may be differences in terms of proprioception and interoception when comparing FM patients with HC. Our findings highlight the complex interplay of sensory and motor impairments in FM, warranting further investigation to clarify underlying mechanisms and inform targeted interventions for this population.

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Appendices

Appendix A

Figure 11

Experimental Set-up of ROD Task

Figure 12

Display of ROD Task

Figure 13

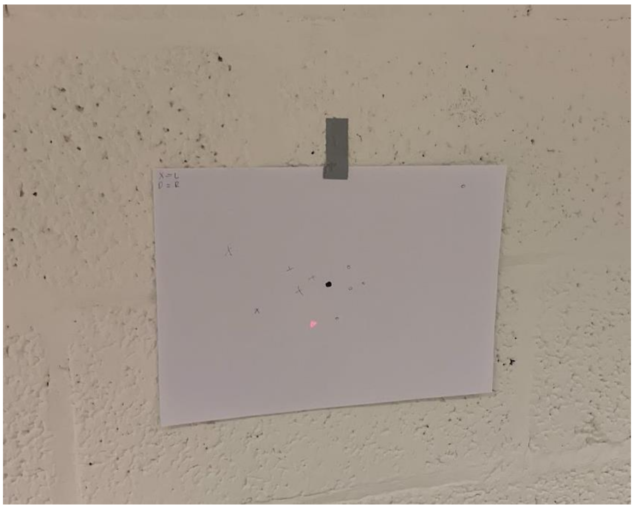
Automated Pneumatic Inflatable Balloon-Type Valve Controller

Appendix B

Figure 14

Experimental Set-up of CJPET

Figure 15



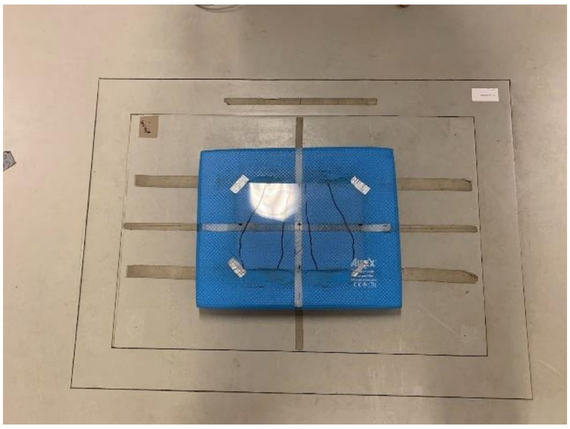
Target of CJPET

Appendix C

Figure 16

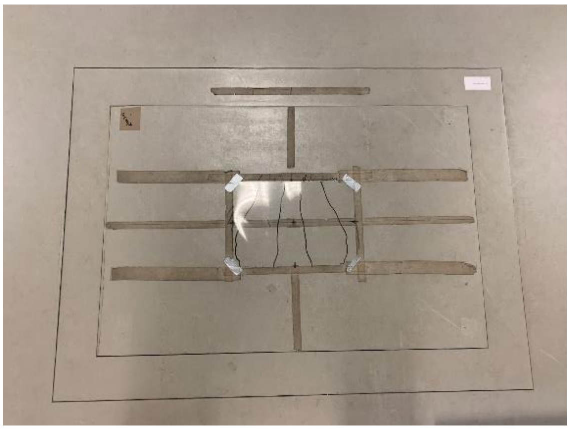
Feet Measurement

Figure 17



Foam Mat on Force Plate

Figure 18

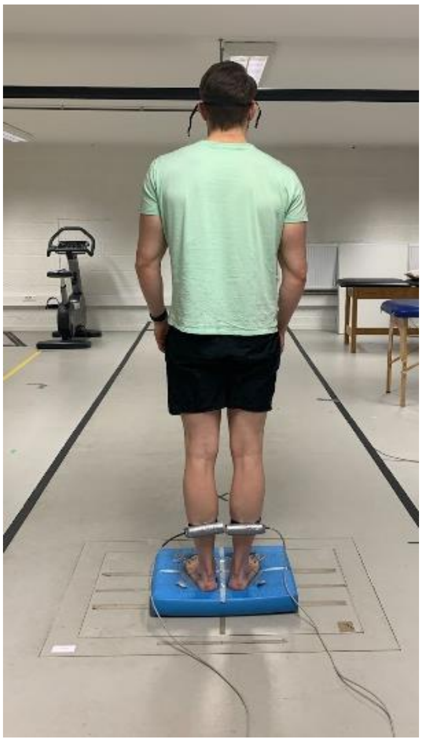


Force Plate with Transparent Foil

Figure 19

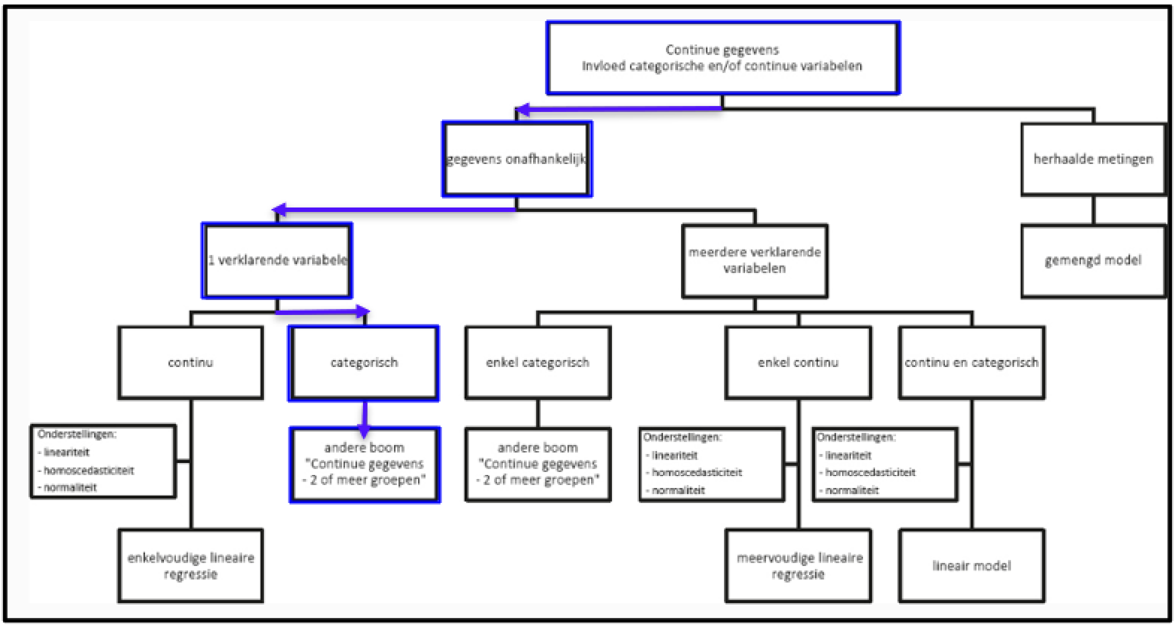
Vibration at the Level of the Back Muscles

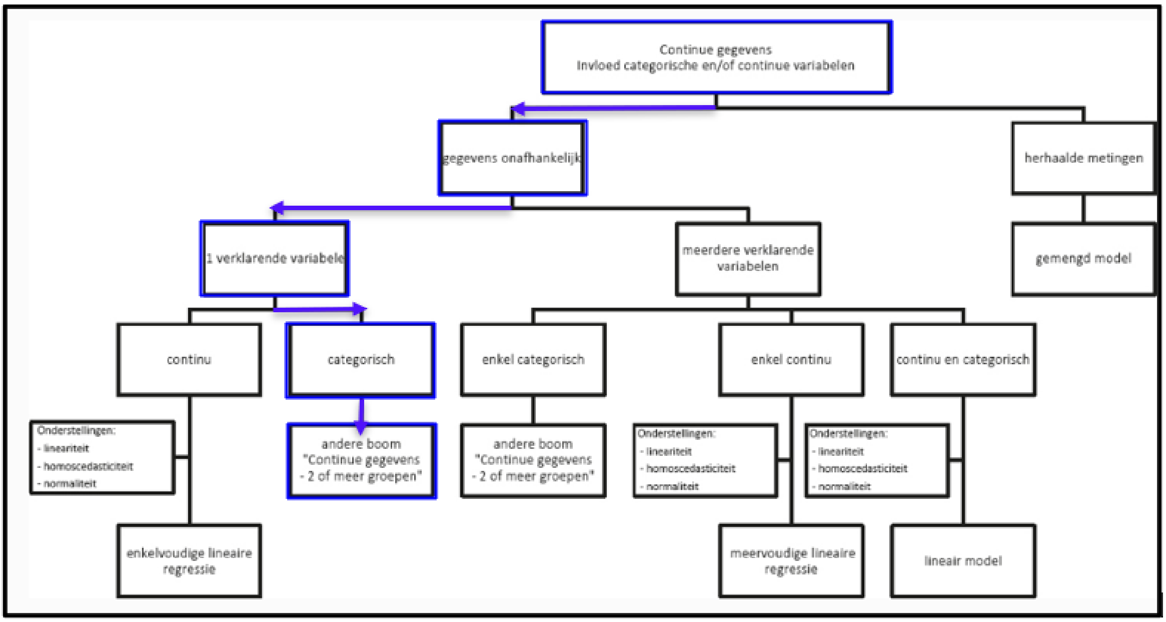
Figure 20

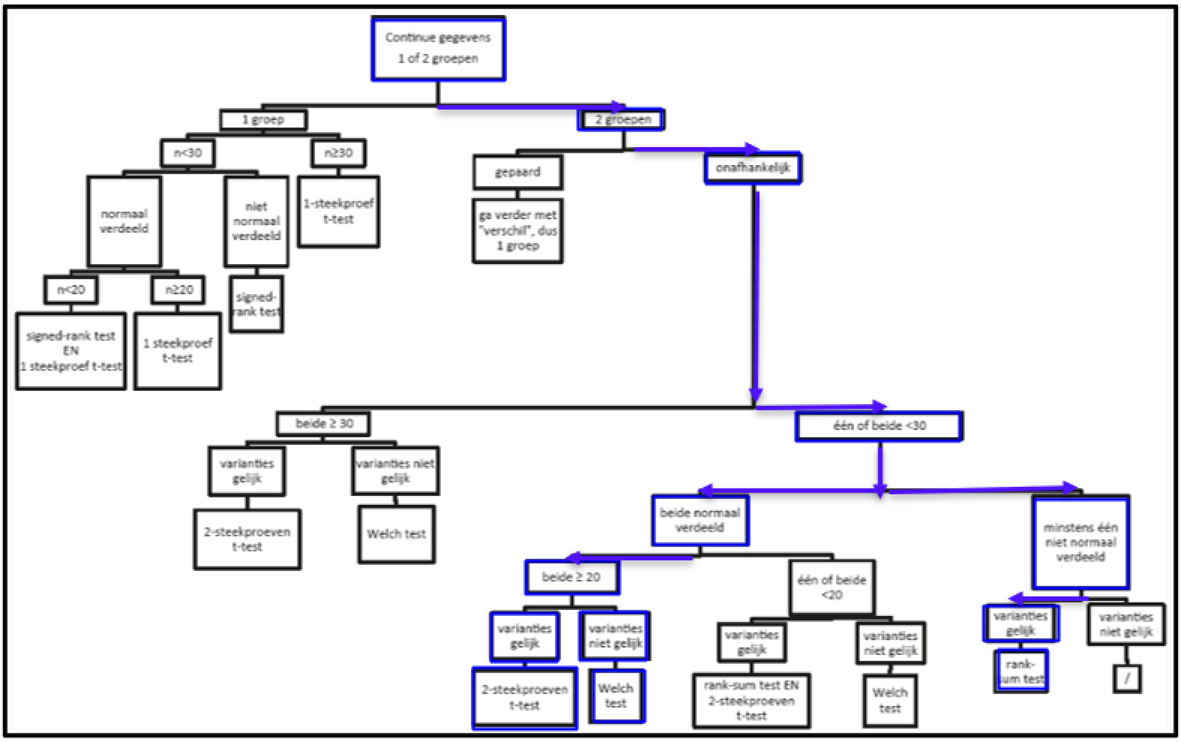


Vibration at the Level of the Ankle Muscles

Appendix D


Continue gegevens
Invloed categorische en/of continue variabelen
gegevens onafhankelijk
herhaalde metingen
1 verklarende variabele
meerdere verklarende variabelen
gemengd model
continu
categorisch
enkel categorisch
enkel continu
continu en categorisch
Onderstellingen:
- lineariteit
- homoscedasticiteit
- normaliteit
andere boom "Continue gegevens - 2 of meer groepen"
andere boom "Continue gegevens - 2 of meer groepen"
Onderstellingen:
- lineariteit
- homoscedasticiteit
- normaliteit
Onderstellingen:
- lineariteit
- homoscedasticiteit
- normaliteit
enkelvoudige lineaire regressie
meervoudige lineaire regressie
lineair model


Continue gegevens
Invloed categorische en/of continue variabelen
gegevens onafhankelijk
herhaalde metingen
1 verklarende variabele
meerdere verklarende variabelen
gemengd model
continu
categorisch
enkel categorisch
enkel continu
continu en categorisch
Onderstellingen:
- lineariteit
- homoscedasticiteit
- normaliteit
andere boom "Continue gegevens - 2 of meer groepen"
andere boom "Continue gegevens - 2 of meer groepen"
Onderstellingen:
- lineariteit
- homoscedasticiteit
- normaliteit
Onderstellingen:
- lineariteit
- homoscedasticiteit
- normaliteit
enkelvoudige lineaire regressie
meervoudige lineaire regressie
lineair model


Continue gegevens
1 of 2 groepen
1 groep
2 groepen
n<30
n≥30
normaal verdeeld
niet normaal verdeeld
1-steekproef t-test
n<20
n≥20
signed-rank test EN 1 steekproef t-test
1 steekproef t-test
signed-rank test
gepaard
onafhankelijk
ga verder met "verschil", dus 1 groep
beide ≥ 30
één of beide <30
varianties gelijk
varianties niet gelijk
2-steekproeven t-test
Welch test
beide normaal verdeeld
minstens één niet normaal verdeeld
beide ≥ 20
één of beide <20
varianties gelijk
varianties niet gelijk
2-steekproeven t-test
Welch test
varianties gelijk
varianties niet gelijk
rank-sum test EN 2-steekproeven t-test
Welch test
varianties gelijk
varianties niet gelijk
rank-sum test
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