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Forearm bisection task suggests an alteration in body schema in patients with functional movement disorders (motor conversion disorders)

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ABSTRACT

Objectives: To explore potential alterations of the Body Schema, the implicit sensorimotor representation of one's own body, in patients with Functional Movement Disorders (FMD, Motor Conversion Disorders), characterized by neurological symptoms of altered voluntary motor function that cannot be explained by typical medical conditions. This investigation is prompted by the potential dissociation from their reportedly intact sense of ownership.

Methods: 10 FMD patients and 11 healthy controls (HC) underwent the Forearm Bisection Task, aimed at assessing perceived body metrics, which consists in asking the subject, blindfolded, to repeatedly point at the perceived middle point of their dominant forearm with the index finger of their contralateral hand, and a psychometric assessment for anxiety, depression, alexithymia, and tendency to dissociation.

Results: FMD patients bisected their forearm more proximally (with an increased shift towards their elbow equal to 7.5%) with respect to HC; average bisection point was positively associated with anxiety levels in the whole sample, and with the tendency to dissociation in the FMD group.

Conclusions: FMD patients perceive their forearm as shorter than HC, suggesting an alteration of their Body Schema. The Body Schema can go through short- and long-term updates in the life course, mainly related to the use of each body segment; we speculate that, despite FMD being a disorder of functional nature, characterized by variability and fluctuations in symptomatology, the lack of sense of agency over a body part might be interpreted by the nervous system as disuse and hence influence the Body Schema, as deficits of organic etiology do.

1. Introduction

Functional Movement Disorders, (FMD, also called Motor Conversion Disorders) are part of the wide spectrum of Functional Neurological Disorders (FND), characterized by neurological symptoms of altered voluntary motor or sensory function that cannot be explained by typical neurological diseases or other medical conditions [1]. FMD includes clinical phenotypes that differ greatly in terms of presentation and severity (e.g., tremor, dystonia, paralysis, gait disorders), although some common clinical features have been identified, including abrupt onset, rapid deterioration of patient's overall functioning, and a fluctuating course [2]. As a matter of fact, FND are a common source of disability in

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medicine; they have been found to be the second most common neurological presenting symptom after headache in outpatient neurology clinics [3] and, because of the elevated number of investigations that patients undergo (the so-called "doctor shopping" phenomenon) and of the level of disability caused by the disorder itself (often leading to loss of employment and need for disability benefit payments), FND have a great economic impact on national health services [4]. It was demonstrated that specific physical rehabilitation [5,6] and psychological interventions [7] can ameliorate FND symptomatology and increase the quality of life of patients with FND; hence, FND can be considered a potentially reversible alteration [8], but its pathophysiology remains unclear. In the last decade, a major line of research trying to integrate psychological, cognitive, and neurobiological factors, focused on the subjective experience that patients feel of their own bodies. It was found that patients with FMD have an abnormal self-directed attention, leading them to overestimate the frequency and the severity of their symptoms [9,10]; they have poor interoceptive accuracy, the perception of sensation coming from within one's own body [11,12]; moreover, they are alexithymic, meaning that they usually present a set of cognitive traits related to the difficulty of identifying and describing one's own feelings and emotions [13]. Finally, FMD patients seem to have an altered sense of agency, the subjective feeling of initiating and controlling a voluntary action, as highlighted by clinical, behavioural [14 – 15], neurophysiological [16], and neuroimaging studies [17]; this is confirmed by several observations: first, their motor symptoms are affected by distraction and entrainment, which are characteristic of voluntary movements [18], but are subjectively experienced as involuntary; second, they were found to have a reduced sensory attenuation [19], and an altered Intentional Binding Effect [20], which is the subjective compression of the temporal interval between a voluntary action and its external sensory consequence; third, patients with functional jerks showed a Bereitschaftspotential (the early cortical activation preceding self-initiated movements in healthy subjects) before involuntary jerks, but not before a common voluntary movement [16]. To understand the potential neurobiological substrate of these phenomena, our group recently conducted a comprehensive literature review on functional neuroimaging in FMD. Our findings revealed decreased activation in the contralateral primary motor cortex and parietal lobe, abnormal activation in the amygdala, and heightened activity in the temporo-parietal junction. Functional connectivity analyses uncovered irregular connections between the amygdala and motor areas (including the Supplementary Motor Area, involved in motor programming), the temporo-parietal junction, and the insula. We proposed that amygdala functional alterations play a pivotal role in the initiation and perpetuation of FMD, and the abnormal functional connectivity between the amygdala and the aforementioned brain regions may explain specific FMD features, including impaired motor conceptualization, motor preparation, inhibition of motor execution, altered sense of agency, and deficits in the cognitive processing of affected body parts [21,22].

On the other hand, the sense of body ownership (the sense that one's own body belongs to oneself) seems to be not impaired in patients affected by FMD, as demonstrated through the well-known Rubber Hand Illusion (RHI) paradigm [23]: the authors suggested that the multimodal integration of sensory and visual stimuli into the Body Schema is therefore intact. Further considerations are needed to confirm this result. The Body Schema is one of the multiple aspects of the body representation that our brain constructs, and has been defined as "*an unconscious functional sensorimotor map of the body based on the information one needs in order to move one's own body (e.g., bodily posture and position, bodily constraints like size and strength of the limbs, kinematical constraints like the degree of freedom of the joints, etc)*" [24,p. 439]. It is built based on proprioceptive sensations coming from one's own muscles and joints, and from both efferent and afferent sensations of movement, and allow oneself to efficiently program an action, basing on the estimated current position of the body and its desired position when the action is completed. Hence, the Body Schema has been proved to be both plastic (dynamically updating itself according to sensory and proprioceptive input) and stable (our body is symmetrical, and its various parts occupy precise reciprocal positions), a fundamental element to allow a sense of continuity of the self [25–27]. De Vignemont [24], in her "spatial hypothesis of the sense of ownership", initially argued that the sense of ownership has its roots in the Body Schema, which also brings first-person perspective. On the other hand, several critiques were moved, arguing that the Body Schema alone is not sufficient to explain the phenomenology of ownership, embodiment, and agency; as a matter of fact, it was difficult to explain the multiple possible pathological disruptions of body representation, such as the Phantom Limb Syndrome (where patients, after having undergone the amputation of a limb, continue to perceive sensations and pain from it, as if it was still there) solely through the notion of Body Schema. Alternative models were proposed, underlying the role of Body Image: this is defined as the conscious representation of how one's body is observed in the third person perspective, influenced by visual inputs, semantic knowledge relating to the body, and consequently socio-cultural, emotional, and affective factors [28,29]; Carruthers [30] proposed an alternative model where offline representations of Body Image underlies the sense of embodiment; others have instead tried to integrate the concepts of Body Schema and Body Image, suggesting that, although they originate from two different information processing systems within the brain, they concur in the construction of body representation [31]. Concerning FMD, although the sense of body ownership resulted intact [23], clinical observations suggested a possible abnormality in central Body Schema representation: Edwards et al. [32] reported the cases of patients with fixed dystonia (a subtype of FMD) with a strong desire for amputation of the affected limb, ultimately resembling a form of Body Integrity Identity Disorders - a condition where affected individuals report a sense of inadequacy of their body because of the presence of an undesired limb that does not match their "inner self body image", ultimately causing significant anxiety and discomfort [33]. Moreover, the authors described the same clinical phenomenon in patients with Complex Regional Pain Syndrome (CRPS1) who, as FMD, showed a normal RHI [34]. Edwards and colleagues [32] ultimately suggested that FMD and CRPS1 could share a common Body Schema alteration, probably due to a painful peripheral stimulus acting as a trigger to destabilize it. Taken together, these findings might suggest that Body Schema and sense of ownership could be somehow dissociable: the former might be altered with respect to healthy controls, but other factors occur in allowing the sense of body ownership and embodiment to be intact or, more specifically, to allow patients with altered Body Schema to fall in the illusion of the RHI as healthy subjects do. To the best of our knowledge, no study has, so far, directly investigated the Body Schema in patients with FMD through a paradigm specifically designed to assess the perceived body metrics (and eventually its plasticity). Hence, the aim of the present study was to compare the spatial estimation of body parts length in a sample of patients with FMD with respect to a group of healthy controls (HC).

2. Materials and methods

2.1. Participants

Eleven consecutive participants with FMD were recruited at the tertiary-level neuropsychiatric clinic of ASST Santi Paolo e Carlo, Presidio San Paolo, Milan. Diagnosis of FMD was made by a neurologist and a psychiatrist according to DSM-5 and to Gupta and Lang diagnostic criteria [18] with the presence of distractibility maneuvers and the demonstration of positive signs. Moreover, a thorough medical examination was performed by a board-certified attending physician, specialized in psychiatry with expertise in neuropsychiatry (BD). Firstly, demographic information, including age, biological sex, self-declared gender identity, and ethnicity, was gathered. Secondly, an evaluation

encompassing potential general medical, neurological, and health-related factors, at the time of the testing and at the anamnestic level was conducted; this included the evaluation of the potential presence of autoimmune diseases, chronic conditions, and other relevant considerations, taking into account both conditions self-reported by the patient and documented by other specialists. Finally, a detailed psychiatric interview was performed, covering both the patient's diagnostic symptoms and potential personality disorders.

Eleven gender- and age-matched healthy subjects were recruited from the researchers' acquaintances and served as a control group (HC). Their health state was investigated through a detailed anamnestic interview. Exclusion criteria were: (i) age below 18 years or above 70 years; (ii) FMD severely affecting the tested (upper) limb; (iii) history of neurosurgery; (iv) psychotic disorders; (v) inability to understand the experimenters' instruction. All participants signed a written informed consent. The study was approved by the Ethics Committee of "Milano Area 1" ("Registro Sperimentazioni n.2020/ST/284", 02/03/2022, Protocol N0010811).

2.2. Procedure

The experiment was conducted in a soft-lighted, sound-attenuated room. Upon arrival, participants underwent a detailed interview to collect demographic and clinical information, and completed: (i) the Edinburgh Handedness Questionnaire [35] to establish their dominant hand: if the score was >0 the right upper limb was tested, if it was <0 the left upper limb was tested; (ii) the Beck Depression Inventory-II and the Beck Anxiety Inventory, to respectively assess the levels of depressive and anxiety symptoms [36–37]; (iii) the Toronto Alexithymia Scale – 20 items (TAS-20): a Total Score was calculated, and participant scoring above the cut-off of 51 were considered alexithymic; three subscales, Difficulty Identifying Feelings (DIF), Difficulty Describing Feelings (DDF), and Externally-Oriented Thinking (EOT) were calculated according to the authors' instructions [38]; (iv) the Dissociative Experience Scale (DES); a Total Score was calculated and participant scoring equal or above the cut-off of 30 were considered at risk of pathological dissociation; three subscales, Dissociative Amnesia, Dissociative Functioning, Depersonalization-Derealization were calculated according to the authors' instructions [39].

Then, participants were asked to comfortably sit at a table and to position their forearms in a parallel position in front of them. The experimenter measured the length of the tested forearm, considering it from the elbow to the tip of the middle finger. Participants were blindfolded and were instructed to point at the middle of the tested limb with the contralateral hand; pointing movements had to be as straight and fast as possible, without online corrections once started. Participants performed three separate sessions of 10 pointing movements each; hence, a total of 30 repetitions per subject was collected. We measured the subjective midpoint (i.e., the distance between the middle fingertip and the point indicated by the subject) in each trial, and calculated a ratio as follows: B = subjective midpoint / total length of the forearm [40].

2.3. Statistical analysis

Statistical analyses were run in Statistical Package for Social Science (SPSS), version 28 ($\alpha \leq 0.05$ deemed significant, all tests were two-tailed). First, the Kolmogorov-Smirnov test was implemented to check that each variable followed a normal distribution; subsequently, descriptive statistics were calculated for demographic and psychometric variables; these were compared between the two groups either via *t*-test for independent sample (continuous variable) or χ squared (categorical variables). t-test results are reported according to Levene's test for homogeneity of variance. Bisection B values were analyzed through a linear mixed model, with Subject as the clustering variable (random intercept), the proportion of bisection B as the dependent variable, and Group (HC vs FMD) as the independent variable, with respect to which the fixed effect was calculated. Finally, Pearson's correlational analyses were run for two primary purposes: 1) to examine the potential association between the average bisection values and the age of participants, considering the wide age range within our participant group; 2) to assess the presence of an association between psychometric variables and the average bisection value of each participant. To address the issue of multiple comparisons, Bonferroni's correction (with a factor of 10) was applied, leading to an adjusted significance level of 0.05/10 = 0.005.

3. Results

One participant with FMD was not able to complete the experiment because of severe pain in the tested limb and was therefore excluded from the study; hence, the final sample included 10 patients with FMD and 11 HC. With respect to psychiatric comorbidities, two patients were also diagnosed with an anxiety disorder, while one patient with Major Depressive Disorder; no one had a personality disorder. Other medical comorbidities were: scoliosis, osteoporosis, and extrasystole (1); irritable bowel syndrome and gastritis (1); suspect of fibromyalgia and hypertension (1); high cholesterol (1); asthma (1). Further clinical details are reported in Table 1.

Kolmogorov-Smirnov test showed that all variables followed a normal distribution (HC: all $df = 10$, all $p > 0.050$; FMD: all $df = 9$, all p > 0.050) except for the variable Handedness (HC: $p = 0.047$, FMD: $p = 0.001$).

The two groups were matched for age, sex, handedness, BMI, and total length of the tested limb (all p > 0.050). Patients with FMD reported higher levels of depression as per BDI-II (p = 0.001), of anxiety as per BAI ($p < 0.001$), of alexithymia as per TAS-20 Total Score ($p = 0.016$) and TAS-20 EOT ($p = 0.047$), and of dissociative symptomatology as per DES Total Score ($p = 0.012$) and DES Dissociative Functioning ($p = 0.011$). Three patients with FMD scored above the cut-off at both the TAS-20 and at the DES. FMD patients bisected their forearm significantly more proximally compared to HC ($F(1, 19) = 16.262$, $p = 0.001$): in particular, FMD patients showed a proximal shift (i.e., the distance from the top of the middle finger towards the elbow) equal to the 76.1% of their forearm [CI: 73.3%; 79.0%], while HC a proximal shift equal to the 68.6% of their forearm [CI: 65.9%; 71.3%] (Fig. 1); hence, the difference between the two groups resulted in a proximal shift of 7.5%. Further statistical details are reported in Table 2.

Correlational analysis in the whole sample, as corrected for multiple comparisons, showed that the average bisection point was positively associated with anxiety levels ($r = 0.617$, $p = 0.004$); in the FMD group, a trend towards corrected significance emerged only for the positive association between the average bisection point and the DES subscale Dissociative Amnesia ($r = 0.800$, $p = 0.010$).

No significant correlation emerged between the age of participants and their average bisection point. Further details are reported in Table 3.

4. Discussion

The present study aimed to compare the spatial estimation of body parts length in a sample of patients with FMD with respect to a group of healthy controls. We implemented the forearm bisection task, a paradigm widely adopted in the literature to study perceived body metrics [41,42], consisting in asking the subject, while blindfolded, to repeatedly indicate the perceived middle point of their dominant forearm with the index finger of their contralateral hand.

Our main finding was that patients with FMD bisected their forearm significantly more proximally (with an increased shift towards their elbow equal to 7.5%) with respect to HC; in other words, they seem to perceive their forearm as shorter than HC do, a result that could be interpreted as an alteration of the Body Schema. The literature showed that human individuals are able to accurately estimate the length of their own body: using the forearm bisection task, it was shown that

Table 1
FMD Group: main symptoms.

ID	Sex	Age	Main FMD Symptom	Psychiatric comorbidities	Medical comorbidities
FMD1	F	62	Right lower limb weakness	Anxiety Disorder	Scoliosis, osteoporosis, extrasystole
FMD2	M	39	Lower limbs weakness	Anxiety Disorder	High cholesterol
FMD3	F	31	Gait disorder	None	None
FMD4	M	69	Dystonia	None	None
FMD5	M	27	Gait disorder	None	None
FMD6	F	67	Weakness	None	None
FMD7	M	39	Gait disorder	None	Gastritis
FMD8	F	54	Lower limbs dystonia	None	Suspect of fybromyalgia, hypertension
FMD9	M	63	Gait disorder	None	Ashtma
FMD10	F	52	Right lower limb weakness	Major Depressive Disorder	None
FMD11 (excluded)	F	39	Right weakness	None	Hashimoto's thyroiditis

Abbreviations: FMD = Functional Movement Disorders; F = Female; M = Male.

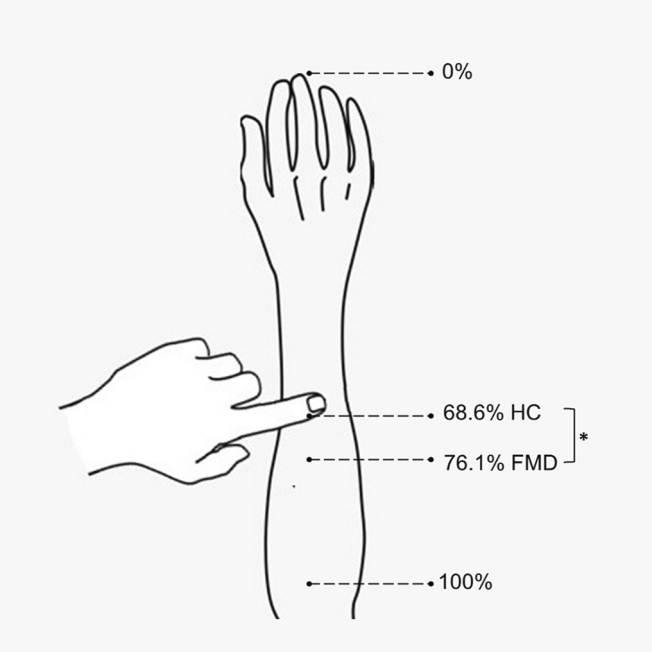

Fig. 1. Graphic representation of the average subjective midpoint (i.e., the distance between the middle fingertip and the point indicated by the subject) during the Forearm Bisection Task for Healthy Controls (HC, 68.6%) and patients with Functional Movement Disorders (FMD, 76.1%). The statistically significant difference indicates that FMD patients perceive their forearm as shorter than HC, suggesting a potential alteration in their Body Schema.

healthy subjects and even right-brain damaged patients with neglect [43,44] are more accurate in detecting the half-point of their forearm (and hence coding its own extension), as compared to a three-dimensional extracorporeal object of identical length. This internal body representation is capable of being updated, should circumstances demand it. Both long-term processes and short-term events (such as a repeated movement) can cause chronic or temporary changes in the representation of perceived body metrics, respectively. In fact, with the same paradigm, the following phenomena were demonstrated. (i) Healthy subjects estimate the mid-point of their forearm to be more distal following a 15-min training with a 60 cm-long tool as compared to pre-tool use, a finding compatible with an increased representation of the participants' forearm length [40], and with an embodiment of the tool in their body representation (i.e., feeling sense of ownership over the tool itself) [45]. (ii) Healthy controls and hemiplegic patients undergoing the Mirror Box Illusion (MBI, another well-known paradigm based on a bodily illusion evoked by the congruency of visual and proprioceptive stimuli related to body limbs) showed a distal shift of the perceived mid-point after performing a motor task during the MBI, indicating an enhanced hand embodiment [46], while schizophrenic patients did not [47]. Hence, there can be positive plastic changes (like skill learning and general development), but also negative ones, as occurs in post-stroke patients who experience immobilization or 'disuse' of a body part [46]. It seems, therefore, that being unable to (correctly) move one's limb leads to an altered brain representation of that body part. As mentioned above, alterations of the Body Schema can be temporary (as seen in the RHI and MBI showing temporarily increased or decreased embodiment of a non-self object) or extended in time (as seen in general skill development or in patients with organic limb pathologies). This begs the question: can these concepts be applied to FMD, a disorder of functional nature, that is characterized by variability, fluctuations in symptomatology, and specifically voluntary movements? Is the lack of sense of agency over a body part in a functional disorder interpreted by the nervous system as disuse, in the same way as a deficit caused by organic etiology? The fact that patients with FMD do not present altered body ownership, as indicated by the finding of Demartini et al. [23] using the Rubber Hand Illusion, suggests that although FMD patients may not experience the functional movement-related symptoms as voluntary (i.e. they lack sense of agency on that movement), they are aware that it is their body that is being subjected to that movement [23]. Therefore, it is possible that the brain of an FMD patient perceives functional motor symptoms as the disuse of a body part, in the same way as the brain of a stroke patient perceives the deficit of the affected body parts. Consequently, it should not be assumed that the Body Schema is unaltered when body ownership is, and it is possible that Body Schema and sense of ownership are dissociated [23,32]. Two further considerations must be made, given that functional symptoms have a fluctuating phenomenology (unlike organic symptoms). On one hand, we should ask ourselves if fluctuating symptoms can cause progressive negative plastic changes in the Body Schema that remain even under conditions of rest. Considering that the Body Schema serves to allow the execution of a motor task, it is subject to minor and temporary modifications which allow the correct performance of those motor tasks. These changes may become gradually reinforced when such tasks are performed frequently, such that the updated Body Schema necessary for using a tool remains 'saved' to be used when needed, without requiring re-calculation each time. This phenomenon is linked to brain plasticity and allows for implicit motor learning. Moreover, there is evidence that rehabilitation-oriented interventions can have a long-term positive effect on plasticity [48,49]. If such punctual interventions can positively affect brain plasticity in the long term, there is no reason to believe that functional symptoms cannot induce the same effect (i.e., long-term alterations in the Body Schema) in the opposite direction, over time. On the other hand, we should also address the hypothesis that that there is a more permanent nature in FMD. The variability and distractibility typical of FMD patients and the 'episodic' nature of the clinical presentation are undeniable; but what if the underlying dysfunctional mechanisms are always present, even when not performing a voluntary movement? Neuroimaging studies on FMD patients conducted in resting conditions

Table 2
Demographic and psychometric assessment.

	HC	FMD	t / χ / F	df	p	Cohen's D
Gender, F/M	4/7	4/6	1.173	1	0.279	NA
Age, mean (SD)	46.0 (16.7)	50.4 (15.5)	−0.063	19	0.540	−0.273
Handedness, mean (SD)	0.6 (0.5)	0.5 (0.6)	0.447	19	0.660	0.195
BMI, mean (SD)	22.8 (2.9)	25.3 (3.7)	−1.715	19	0.103	−0.749
Length of the tested limb, mean (SD)	43.6 (2.9)	43.1 (3.8)	0.321	19	0.751	0.140
BDI – II Total Score, mean (SD)	4.6 (3.9)	21.9 (10.2)	−4.804	9.928	**0.001**	−2.336
BAI Total Score, mean (SD)	2.7 (3.1)	23.2 (9.5)	−6.214	9.371	**<0.001**	−3.044
TAS-20 Total Score, mean (SD)	36.3 (5.2)	48.2 (11.6)	−2.861	10.566	**0.016**	−1.381
TAS-20 Total Score, above/below cut-off	0/11	3/9	NA	NA	NA	NA
TAS-20 DIF, mean (SD)	11.3 (3.7)	16.7 (7.7)	−1.931	10.939	0.080	−0.928
TAS-20 DDF, mean (SD)	10.3 (2.3)	12.6 (5.3)	−1.282	18	0.216	−0.576
TAS-20 EOT, mean (SD)	14.7 (3.0)	19.0 (5.8)	−2.131	18	**0.047**	−0.958
DES Total Score, mean (SD)	7.1 (6.1)	24.4 (15.9)	−3.088	9.935	**0.012**	−1.502
DES Total Score, above/below cut-off	0/11	3/9	NA	NA	NA	NA
DES Dissociative Amnesia, mean (SD)	4.6 (4.6)	13.6 (12.2)	−2.104	9.859	0.062	−1.024
DES Dissociative Functioning, mean (SD)	11.7 (10.3)	36.2 (22.2)	−3.048	10.801	**0.011**	−1.467
DES Depersonalization – Derealization, mean (SD)	2.3 (3.0)	18.1 (25.1)	−1.869	8.188	0.098	−0.932
Forearm bisection B, mean [95% C.I.]	68.6% [65.9%; 71.3%]	76.1% [73.3%; 79.0%],	16.262	1, 19	**0.001**	NA

Abbreviations: BAI = Beck Anxiety Inventory; BDI-II = Beck Depression Inventory Second Version; C.I. = Confidence Interval; DES = Dissociative Experience Scale; DIF = Difficulty Identifying Feelings; DDF = Difficulty Describing Feelings; df = degrees of freedom; EOT = Externally-Oriented Thinking; FMD = Functional Movement Disorders; F = Female; HC = Healthy Controls; M = Male; SD = Standard Deviation TAS-20 = Toronto Alexithymia Scale 20 Items.

Table 3
Correlational analysis.

		Average bisection point Overall sample	Average bisection point HC group	Average bisection point FMD group
Age	r	0.279	0.436	0.031
	p	0.220	0.180	0.933
BDI-II	r	0.347	0.007	−0.583
	p	0.134	0.984	0.099
BAI	r	**0.617****	0.467	0.034
	p	**0.004**	0.147	0.931
TAS-20 Total Score	r	0.382	−0.287	0.147
	p	0.097	0.392	0.706
TAS-20 - DIF	r	**0.451***	−0.106	0.481
	p	**0.046**	0.757	0.190
TAS-20 DDF	r	0.023	−0.326	−0.216
	p	0.925	0.328	0.577
TAS-20 EOT	r	0.213	−0.110	−0.146
	p	0.366	0.747	0.708
DES Total Score	r	**0.477***	−0.375	0.379
	p	**0.033**	0.256	0.314
DES Dissociative amnesia	r	**0.588***	−0.223	**0.800****
	p	**0.006**	0.511	**0.010**
DES Dissociative functioning	r	**0.466***	−0.359	0.397
	p	**0.038**	0.279	0.290
DES Depersonalization derealization	r	0.195	−0.505	−0.140
	p	0.410	0.113	0.719

Abbreviations: BAI = Beck Anxiety Inventory; BDI-II = Beck Depression Inventory Second Version; DES = Dissociative Experience Scale; DIF = Difficulty Identifying Feelings; DDF = Difficulty Describing Feelings; EOT = Externally-Oriented Thinking; FMD = Functional Movement Disorders; HC = Healthy Controls; r = Pearson's r; TAS-20 = Toronto Alexithymia Scale 20 Items; * = significative for $p < 0.05$ (uncorrected for multiple comparisons); ** = significative for $p < 0.005$ (corrected for multiple comparisons).

reveal structural [50], functional [51–55], and neurochemical [56] alterations that are not present in healthy controls. Therefore, it can be hypothesized that in FMD the impaired mechanism that concerns the origin and correct execution of a voluntary action does not merely emerge during its (attempted) performance; it is instead present, 'under the surface' even during resting conditions. Moreover, it is important to note that our study was testing upper limbs only, and we excluded patients with FMD with symptoms directly affecting the upper limbs, as they might not have been able to perform the movement at all; hence, it remains to be investigated why our patients mainly suffering from lower limbs, posture, and gait symptoms would show a shrinkage in their upper limb representation. Our result might point towards the direction of a generalized alteration of the Body Schema, but further studies are needed (i.e., comparing patients with and without upper limbs functional symptoms) to shed light on this point.

With respect to the psychometric variables, our data confirm that patients with FMD show higher alexithymic traits than HC, together with symptoms of anxiety and depression, and a tendency to dissociation. In our entire sample, higher levels of anxiety were found to be associated with a more proximal average subjective forearm midpoint, while depression and alexithymia were not. Alterations in body representation have been previously demonstrated to be linked with anxiety, particularly in the field of Eating Disorders (with a specific focus on body image [57]). This association is also observed in specific conditions where the Body Schema appears altered, as seen in the previously mentioned Body Integrity Identity Disorder [33]. Moreover, anxiety disorders can sometimes be associated with distorted perceptions of one's body or bodily sensations [58]. We might speculate that our results, indicating that levels of anxiety are related to stronger Body Schema shrinkage, might suggest that even in non-pathological anxiety states, there exists an association with the perception of one's own body.

Not surprisingly, in patients with FMD only, a strong positive association emerged between the proportion of forearm bisection and the DES subscale Dissociative Amnesia. It is not new that dissociation plays an important role in the maintenance (and possibly the exacerbation) of Functional Neurological Disorders, across various phenotypes. Numerous studies have identified aspects of detachment and compartmentalization in patients with FMD and Psychogenic Non-Epileptic Seizures (PNES), as evidenced by both experimental findings and self-report data [59–61]. Moreover, it is intuitively clear that phenomena such as dissociative experiences are directly linked to anomalies in one's own body representation. However, distinct subtypes of FND exhibit differences in terms of personality traits, potential traumatic history (e.g., abuse, neglect), and factors contributing to dissociative phenomena [62,63]. Therefore, future studies should aim to directly investigate the extent to which the tendency towards dissociation impacts the malleability of the Body Schema in FMD and should explore the specificity of this impact in comparison to PNES and other FND phenotypes.

4.1. Limitations, conclusions, and future perspectives

The main limitation of this study is the small sample size, although in line with similar research studies conducted on the same population; future studies with larger samples should investigate potential differences between FMD sub-groups with different phenotypes (i.e., weakness, dystonia, gait disorders, tremor, etc). Furthermore, while we administered various questionnaires to explore comorbid symptoms, our examination did not delve deeply into potential histories of trauma, abuse, and neglect; as another constraint imposed by the small sample size, we encountered challenges in conducting a comprehensive comparison of patients based on officially diagnosed comorbidities. Second, although we investigated in our sample most of the traits previously assessed in studies on FMD (such as anxious-depressive symptoms and alexithymic traits), we did not evaluate their interoceptive accuracy and self-directed attention, and hence we could not properly study their association with the Body Schema alteration that we found. Third, all participants performed the bisection movement with their non-dominant hand; hence, we cannot rule out the possibility that this might have affected the precision of the bisection, maybe causing the tendency to perceive the forearm shorter than it is; however, it is important to note that all participants (both HC and FMD) were subjected to the same limitation, and the significant difference between the two groups remained. Fourth, we did not analyze whether participants bisected their forearm differently between the three sessions, hence we cannot dismiss the possibility of a habituation effect; however, strict precaution were taken in-between sessions, urging the subjects to move their forearm as much as possible (while not being blindfolded) in order to restore their baseline proprioceptive and visual sensations. Fifth, our control group was not a randomly selected sample from the general population, but consisted of individuals who were acquaintances of the researchers. Last, this study was not pre-registered.

In conclusion, our study suggests that patients with FMD showed an altered Body Schema when compared to healthy controls in a simple task assessing perceived body metrics. Future perspective includes testing whether patients with FMD are susceptible of bodily illusions involving active movements, such as in the Mirror Box Illusion paradigm [47], and assessing whether their Body Schema undergoes any modification given the manipulation of sense of agency.

Author contribution

VN: conceived the study; collected, analyzed, and interpreted the data; drafted the manuscript.

NI, FC: collected, analyzed, and interpreted the data; drafted the manuscript.

GB, CS, FL, SS, LM, RT: collected and interpreted the data.

OG, AP: revised the manuscript for intellectual content.

AM, BD: conceived the study; interpreted the data; revised the manuscript for intellectual content.

CRediT authorship contribution statement

Veronica Nisticò: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Neofytos Ilia:** Writing – original draft, Formal analysis, Data curation. **Giovanni Broglia:** Writing – original draft, Data curation. **Claudio Sanguineti:** Data curation. **Francesco Lombardi:** Writing – original draft, Formal analysis, Data curation. **Silvia Scaravaggi:** Data curation. **Laura Mangiaterra:** Data curation. **Roberta Tedesco:** Data curation. **Orsola Gambini:** Writing – review & editing, Resources, Project administration. **Alberto Priori:** Writing – review & editing, Resources, Project administration. **Angelo Maravita:** Writing – review & editing, Supervision, Resources, Project administration, Conceptualization. **Benedetta Demartini:** Writing – review & editing, Supervision, Resources, Project administration, Conceptualization.

Declaration of competing interest

none.

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