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Exploring specific alterations at the explicit and perceptual levels in sense of ownership, agency, and body schema in Functional Motor Disorder: A pilot comparative study with Irritable Bowel Syndrome

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A R T I C L E I N F O

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A B S T R A C T

Functional Motor Disorders (FMD) consists in symptoms of altered motor function not attributable to typical neurological and medical conditions. This study aimed to explore

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explicit and perceptual measures of Sense of Ownership, Agency, and Body Schema in FMD patients, and assess whether these alterations are specific to FMD or shared with other functional disturbances. Twelve FMD patients, ten with Irritable Bowel Syndrome (IBS, a functional gastrointestinal disorder) and fifteen healthy controls (HC) underwent: (i) the Mirror Box Illusion (MBI), requiring participants to perform tapping movements with their dominant hand concealed from sight, while visual feedback was provided by an alien hand under visuo-motor congruency or incongruency conditions; (ii) a Forearm Bisection Task before and after exposure to the MBI, and the Embodiment Questionnaire after the MBI, as perceptual and explicit indices of the embodiment illusion, respectively. At the Embodiment Questionnaire, all groups self-reported embodiment of the alien hand only under visuo-motor congruency; at the perceptual level, HC showed the expected distalized drift (an "elongated" arm in the Body Schema) under visuo-motor congruency, while FMD and IBS patients did not. FMD patients showed a proximalized drift when sensory feedback mismatched, possibly reflecting reliance on altered priors to avoid losing control over their movement. Results in IBS patients suggest Body Schema alterations differ across functional syndromes. In conclusion, we found that explicit Sense of Ownership and Agency are preserved in FMD and IBS patients, but dissociate from their implicit measures, differing in degree according to the specific disturbance.
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1. Introduction

Functional Motor Disorders (FMD), a common phenotype of Functional Neurological Symptom Disorder (also known as Conversion Disorder), are characterized by neurological symptoms of altered voluntary motor or sensory function that cannot be attributed to typical neurological diseases or other medical conditions (American Psychiatric Association, 2021), but nevertheless are authentic, cause impaired functioning in patients' everyday life (Carson & Lehn, 2016), and are associated with high rates of comorbid mental health conditions (Carson et al., 2011). FMD manifest in diverse ways, including hyperkinetic motor symptoms such as tremor, myoclonus, dystonia, or paroxysmal dyskinesia; hypokinetic motor symptoms such as weakness and parkinsonism; and impairments in walking, balance, or posture. Despite being potentially reversible, FMD are a significant source of disability, often resulting in unemployment, reliance on disability benefits, and substantial costs to healthcare systems (Carson et al., 2011; Carson & Lehn, 2016). The prevalence of FMD is estimated at around 5% (American Psychiatric Association, 2021), with onset typically in adolescence or early adulthood, though cases occur in both childhood (Paleari et al., 2022) and older age (Geroin et al., 2024). The condition is more common in women than men, with a female-to-male ratio of 2:1 to 10:1 (McLoughlin, 2023), and it is more frequently observed in individuals from lower socioeconomic backgrounds (Levenson & Sharpe, 2016). Early hypothesis related to FMD pathophysiology, rooted in the Freudian psychoanalytic theory, attributed functional symptoms to repressed psychic conflicts, particularly sexual drives, leading to the term "conversion disorder". Although the term persists in the DSM-5-TR, contemporary research has shifted toward a bio-psycho-social model, integrating psychological and neurobiological perspectives (Levenson & Sharpe, 2016).

Functional motor symptoms are typically improved by distraction and enhanced by attention (Gupta & Lang, 2009); yet, they are subjectively experienced as involuntary by patients with FMD. Hence, a major line of research suggests that FMD patients might suffer from alterations in the Sense of Agency (Nahab et al., 2017; Seghezzi et al., 2021), the subjective feeling of initiating, performing and controlling a voluntary action, and owning its effects in the environment (Haggard, 2017). Movements are initiated by the motor cortex following planning in the supplementary motor area; in a predictive coding framework, this it thought to generate feedforward signals that, after movement performance, are compared to proprioceptive and sensory feedback: if these match, sense of agency arise; if not, the movement is not perceived as voluntary. Mismatch between predictive and actual feedback creates prediction error, which update the model so that the prediction will match the subsequent feedback. In FMD, it is hypothesized that the model is not accurately updated, due to an overweighting of the feedforward message influenced by prior expectations, attention, and emotion (Edwards et al., 2012; Hallett et al., 2022).

Evidences of altered Sense of Agency are abundant in FMD: these patients showed impaired feeling of intention before movements (Edwards et al., 2011b), reduced "intentional binding effect" (Kranick et al., 2013) (the subjective compression of the temporal interval between a voluntary action and its external sensory consequence (Haggard et al., 2002)), and reduced sensory attenuation (Macerollo et al., 2015; Pareés et al., 2014) (the phenomenon whereby sensations resulting from one's own actions are reduced (Blakemore et al., 1998)). These impairments may contribute to the brain's inability to recognize self-generated actions as such. In contrast, Marotta and colleagues (Marotta et al., 2017) implemented the moving Rubber Hand illusion (RHI), where participants' right hand, performing a tapping movement, was hidden inside a box, while a realistic rubber right hand seen by the participants performed the same movement synchronously or asynchronously. They found that both FMD patients and HC reported a higher Sense of Agency in the synchronous condition with respect to the asynchronous condition, suggesting that the explicit Sense of Agency is preserved in FMD. Given the central role of the Sense of Agency in FMD, it is important to explore its interplay with other body representation constructs, such as the Sense of Ownership and the Body Schema.

1.1. The role of sense of agency, ownership, and body schema in FMD

The awareness of being the actor of one's own actions (Sense of Agency) is crucially linked to: (i) the sense that one's body belongs to oneself (Sense of Ownership); (ii) the integrity of the Body Schema, an unconscious sensorimotor map that integrates multisensory and motor signals, guiding movement planning and execution; and (iii) the experience of Embodiment, i.e., the sense of being located within one's own bodily boundaries (Braun et al., 2018). The integration of coherent bodily-related multisensory and sensory-motor signals seems crucial for bodily experiences to arise (Azañon et al., 2016).

The Body Schema is formed through proprioceptive input from muscles and joints, as well as both efferent and afferent movement-related signals. It enables the planning and execution of actions by estimating the current position of the body and its desired position upon completing the movement. Hence, the Body Schema is both dynamic, constantly updating itself adapting to sensory and proprioceptive changes, and stable, maintaining consistent body part relations to ensure a continuous sense of self. Studies demonstrate that bodily illusions, such as the RHI, the Mirror Box Illusion (MBI, see below), or tool-use paradigms, induce changes in the Body Schema, extending its boundaries to include external objects like tools (Maravita & Iriki, 2004) in both in healthy controls (Rossetti et al., 2020), as well as in patients with neurological conditions such as hemiplegia (Tosi et al., 2018). In these paradigms alterations of the Body Schema are temporary, but they can be more enduring, either positively (as in motor skills development or physiotherapy after injuries) or negatively, as in patients who permanently lose the use of a limb. In fact, these changes are gradually reinforced when tasks are (or are not) frequently performed, allowing the updated Body Schema to remain “saved for future use”, without requiring recalculation each time. This phenomenon is linked to brain plasticity and enables implicit motor learning (Dohle et al., 2009; Mály & Dinya, 2008).

While the Sense of Ownership has been found intact in FMD patients through paradigms like the RHI (Demartini et al., 2016; Marotta et al., 2017), our group previously demonstrated, through the Forearm Bisection Task (see below) that FMD patients perceive their forearm as shorter than healthy controls, suggesting a disruption in the Body Schema at resting state, despite preserved ownership (Nisticò et al., 2024). We speculated that this dissociation might suggest that functional symptoms might mimick the effects of disuse due to organic impairments (Tosi et al., 2018), ultimately resulting in Body Schema disruption even at resting state. Such findings emphasize the relevance of studying embodiment and Body Schema in FMD, whose symptoms are characterized by lack of agency. Whether these alterations are unique to FMD compared to other functional disorders remains unclear.

1.2. Aims of the study

The aim of the present study was to investigate the Sense of Ownership, Agency, and potential changes in the Body Schema of patients with FMD by measuring their response to a bodily illusion paradigm during active movements, compared to a group of HC and to a group of patients with Irritable Bowel Syndrome (IBS). The choice of this second control group was intended to investigate whether another functional disorder, defined as such according to Rome IV criteria (Drossman, 2016), not involving the motor system, might also show alterations in body representation-related constructs. To this aim, we implemented the Mirror Box Illusion paradigm (MBI) as in Rossetti et al. (2020), to test the degree of embodiment of an alien hand under three conditions characterized by different levels of visuo-motor congruence (refer to the Method section for details). As previously mentioned, it was shown that HC (Rossetti et al., 2020) and hemiplegic patients (Tosi et al., 2018) undergoing the MBI showed an enhanced Embodiment of the alien hand after the MBI training in the visuo-motor congruency condition, while patients with other neuropsychiatric conditions affecting their Sense of Agency did not (Rossetti et al., 2020). We hypothesized that HC would exhibit a Sense of Embodiment, Ownership, and Agency for the alien hand in conditions of visuomotor congruence. In FMD patients, we assumed an impairment in these aspects, especially in the proprioceptive dimension, due to their altered Body Schema at baseline (Nisticò et al., 2024) and previously reported alterations in their Sense of Agency (Edwards et al., 2011b; Kranick et al., 2013; Macerollo et al., 2015; Maurer et al., 2016; Nahab et al., 2017; Pareés et al., 2014; Seghezzi et al., 2021) but not in their explicit experience of it (Marotta et al., 2017). Given the limited findings on Sense of Ownership and Agency in IBS (Nisticò et al., 2022), we expected that IBS patients would behave similarly to HC, supporting the hypothesis that alterations in Body Schema and Sense of Agency are specific to FMD.

2. Methods

2.1. Participants

Sample size was determined through a priori power analysis using G. Power 3.1: with $\alpha = .05$, Power (1-β) = .80, and effect size = .15 (Cohen, 1988; Rossetti et al., 2020), the required total sample size was minimum $N = 30$.

Thirteen consecutive FMD patients were recruited at the tertiary-level neuropsychiatric clinic of San Paolo General Hospital, Milan (Italy). Diagnosis of FMD was made by a neurologist and a psychiatrist according to DSM-5 and Gupta and Lang diagnostic criteria (Paleari et al., 2022). Ten patients with IBS were recruited at Humanitas Research Hospital, Rozzano (Italy); diagnosis was made by a gastroenterologist according to the Rome IV criteria (Drossman et al., 2016). Fifteen HC were recruited via word-of-mouth amongst hospital staff and acquaintances. Their health state was investigated through a detailed anamnestic interview. Exclusion criteria were: (i) age below 18 years or above 70 years; (ii) presence of FMD or medical symptoms severely affecting the tested limb, compromising the participant's ability to perform the movement; (iii) history of other neurological disease; (iv) psychotic disorders; (v) inability to understand the experimenters' instruction. Participants signed a written informed consent. The study was approved by the Ethics Committee of "Milano Area 1" ("Registro Sperimentazioni n.2020/ST/284", N0010811) and was conducted in accordance with the Helsinki Declaration.

2.2. Sociodemographic and psychometric questionnaire

Participants underwent a detailed interview to collect demographic and clinical information, and completed the following self-administered questionnaires: (i) the Edinburgh Handedness Questionnaire to establish their dominant hand, and consequently testing the right or left upper limb if the score was respectively above or below 0 (Oldfield, 1971); (ii) the Beck Depression Inventory-II (Beck, Steer, & Brown, 1996) and the Beck Anxiety Inventory (Beck & Steer, 1990), to respectively assess the levels of depressive and anxiety symptoms; (iii) the Toronto Alexithymia Scale – 20 items (TAS-20), where participant scoring ≥51 were considered alexithymic (Bagby et al., 1994); (iv) the Dissociative Experience Scale (DES), where participant scoring ≥30 were considered at risk of pathological dissociation (Bernstein & Putnam, 1986); (v) the Sense of Agency Scale (SoAS), a measure of person's general, context-free beliefs about having core agency; two subscales were calculated: the Sense of Positive Agency (SoPA) and the Sense of Negative Agency (SoNA) (Tapal et al., 2017).

2.3. The Mirror Box Illusion

Participants removed any jewelry and rolled up their sleeves, so their arms and hands were completely bare, to help enhance the visual similarity between the experimenter's and the participant's limb during MBI training. The experimental procedure consisted of four phases, to be repeated for three sessions: (i) pre-training forearm bisection task; (ii) MBI training; (iii) post-training forearm bisection task; (iv) post-training questionnaires (Fig. 1). When needed, participants were reminded to keep their limb still to avoid tactile and proprioceptive clues during MBI and bisection tasks; limb movements were encouraged in the breaks between the three experimental conditions, to restore baseline somatic feedback.

2.3.1. MBI training

Participants sat in front of a table facing a Mirror Box, consisting of a wooden box with one mirror placed parallel to participant's midsagittal plane. Participant's dominant limb was placed inside the Mirror Box, hidden from view, with the palm facing down. The experimenter sat next to the participant with their opposite hand placed outside the box with the palm down, in front of the mirror, at approximately 20 cm. In this setting, the experimenter's hand was reflected in the mirror, anatomically and spatially corresponding to the participant's hand inside the box, hence producing a mirror reflection that exactly matched the position of the participant's hand. To reduce visual interference, a white cloth was draped onto participants' and experimenter's shoulder leaving only the mirror surface visible to the participants. Participants were asked to keep their eyes closed throughout the preparation of this setup, and to look directly at the (reflected) hand when opening their eyes. Participants were requested to perform a tapping movement (i.e., raise and lower the index of the hand inside the Mirror Box) while looking at the mirror reflection at a metronome-paced rhythm of 1 Hz. To avoid tactile feedback, they were instructed to never touch the table with their finger (Romano et al., 2013). A second experimenter controlled for the participant tapping at the proper rate during MBI training.

In the three experimental conditions, participants were exposed to three different types of (alien) visual feedback: (i) Synchronous: the experimenter performed the same tapping movement as the participant (i.e., lowering their index finger at every beat); (ii) Asynchronous: the experimenter performed a tapping movement at the same pace of the participants, but in the opposite direction (i.e., raising their index finger at every beat); (iii) Random: the experimenter performed different movements, following casual trajectories and irregular frequency. Each condition lasted 60 s. The order of the conditions was randomized across participants.

2.3.2. Forearm bisection task

Participants positioned their forearms in a parallel position on the table in front of them. Participants were blindfolded and were instructed to point at the middle of the tested limb (considering it from the elbow to the middle fingertip) with the contralateral hand; pointing movements had to be straight and fast, without online corrections. Participants performed ten pointing movements during each bisection task, for a total of 60 repetitions (10 trials × 2 bisection tasks (pre-MBI, post-MBI) × 3 conditions). The experimenter measured the

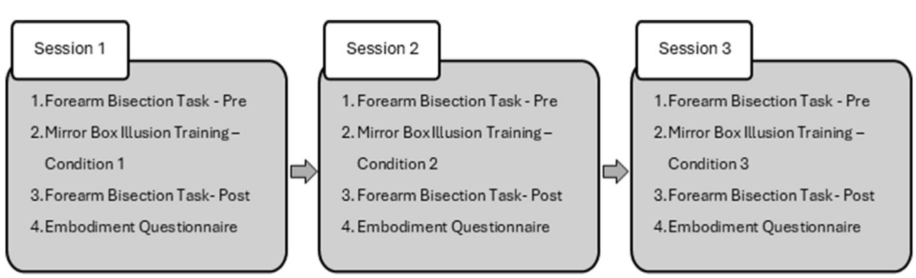

Fig. 1 – Procedure. Condition 1, 2 and 3, corresponding to Synchronous, Asynchronous and Random Mirror Box Training, were randomized across participants.

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 (Sposito et al., 2012). A distal shift in the subjective midpoint was considered as an indication of embodiment of the alien limb (Rossetti et al., 2020; Tosi et al., 2018). To prevent proprioceptive cues from being provided to participants during the entire session, participants were instructed to: 1) avoid touching the table with their finger while tapping; 2) avoid touching their tested forearm with the other hand; and 3) refrain from moving their arm before completing the entire task. Moreover, experimenters took care not to touch the participant's forearm while sitting beside them and draping the aforementioned white cloth over their shoulder.

2.3.3. Questionnaires

At the end of each session, participants retrospectively rated their subjective experience during the MBI training by replying to the first 10 items of the Embodiment Questionnaire by Longo and colleagues (Longo et al., 2008), adapted to the MBI training (Rossetti et al., 2020). Participant had to rate to what extent they agree or disagree with each item by referring to a 7-point Likert scale presented on a sheet of paper (+3: strong agreement; 0: neither agreement nor disagreement; −3: strong disagreement). To rule out participants' response style effect, a within-subject standardization (Fischer & Milfont, 2010) (i.e., ipsatisation: $x' = (x\text{-mean}_{individual})/SD_{individual}$) was implemented as in Rossetti et al. (2020). Items were presented always in the same order. The following three subscales were calculated from ipsatisation rates: (i) Ownership: the feeling that the mirrored hand is likely to belong to one's own body (items 1–5); (ii) Location: a sense of spatial congruency between one's own hand and the mirrored hand (items 6–8); (iii) Agency: the sense of being the agent of the movements performed by the mirrored hand (items 9–10).

2.4. Statistical analysis

Statistical analyses were run in SPSS. v28 ($\alpha \leq .05$ deemed significant). After confirming that variables followed a normal distribution (Kolmogorov–Smirnov test), descriptive statistics were calculated for demographic and psychometric variables, and were compared between groups either via χ squared (categorical variables), or through a series of one-way ANOVA, with Group as between-subject factor, and Bonferroni test for post-hoc comparisons. Results at the Embodiment Questionnaires were analyzed through four separate Repeated Measures ANOVA, with the three conditions (Congruency: Synchronous, Asynchronous, Random) as within-subject factor, Group as between-subject factor (with Bonferroni test for post-hoc comparisons), and the questionnaires subscales (Embodiment, Ownership, Location and Agency) as dependent variables; results are reported according to Mauchly's test for homogeneity of variance, with appropriate correction when needed. Bisection B values were analyzed through a Linear Mixed Model (LMM), with Subject as the clustering variable, the proportion of bisection B as the dependent variable, and Group (HC vs FMD vs IBS), Time (Pre vs Post training) and Congruency (Synchronous, Asynchronous and Random) as independent variables. We tried to fit the complete LMM with a random slope on all fixed and interaction effects but the model did not converge; therefore, our final model present as random slopes only the intercept. This choice resulted in high degrees of freedom for most of the fixed effects, hence our results should be considered cautiously and preliminary. Result pertaining to a subset of the present sample (10 FMD patients, 11 HC), with respect to Forearm Bisection baseline level only (i.e, before MBI training) are reported elsewhere (Nisticò et al., 2024).

Finally, we investigated potential correlations between the psychometric variables and the MBI-related variables (Embodiment Questionnaire and Forearm Bisection Task) via Person's correlational analysis, both in the overall sample and in each single group; Bonferroni correction was applied to account for multiple comparisons.

3. Results

One participant with FMD was not able to complete the experiment because of pain in the tested limb and was therefore excluded from the study; the final sample included 12 patients with FMD, 10 with IBS, and 15 HC. Sociodemographic and clinical features are reported in Table 1.

Groups were matched for age, sex, handedness, BMI, and length of the tested limb (all $P > .05$). With respect to HC, patients with FMD and with IBS showed higher values of: depression as per BDI-II, anxiety as per BAI, and alexithymia as per TAS-20 Total Score (all $P < .05$); no differences were found between FMD and IBS. Only FMD patients scored higher than HC at the DES Total Score and its subscale Dissociative Functioning (all $P < .01$). Three patients with FMD scored above the cut-off at both the TAS-20 and at the DES; one patient with FMD scored above the cut-off at the TAS-20 only. Five patients with IBS scored above the cut-off at the TAS-20 only. Finally, at the SoAS, FMD scored significantly higher than HC at the SoNA component ($P = .022$) (Table 2).

At the Embodiment Questionnaire, there was a significant main effect of Congruency at the Total Score and all its subscales Ownership, Location and Agency (all $P < .05$); the Synchronous condition elicited a higher sense of Embodiment and Ownership over the alien hand with respect to the Asynchronus and the Random condition, and a higher sense of Embodiment, Ownership, Location and Agency over its movement with respect to the Random condition, across all subjects (all post-hoc $P < .04$). There was no significant main effect of Group, or Group × Congruency interaction (Table 3, Fig. 2).

At the Forearm Bisection Task, a significant main effect of the second-level interaction Group × Time × Condition ($F(4, 2284.98) = 2.76$, $P = .026$) emerged. Pairwise Comparisons Bonferroni-corrected showed that: (i) as expected, HC reported a distalization of their average bisection point of the 1.8% ($P < .001$) after the MB training in the Synchronous condition only: before the Synchronous training they pointed at the 69.2% of their forearm [95% C.I.: 65%; 70%], while after the training at the 67.4% of their forearm [95% C.I.: 67%; 71%]); this significant result was not present in the FMD group, nor in the IBS group. (ii) FMD patients showed a proximalization of their

Table 1 – FMD main symptoms and clinical details.

ID	Sex	Age	Main FMD Symptom	Symptoms related to FMD	FMD Onset	Psychiatric comorbidities	Medical comorbidities	Traumatic psychological and physical events in anamnesis
FMD1	F	62	Right lower limb weakness	Pain, Fatigue	Acute	Anxiety Disorder	Scoliosis, osteoporosis, extrasystole	Father's death and surgery (herniotomy)
FMD2	M	39	Lower limbs weakness	Pain, Fatigue, Sleep difficulties	Subacute	Anxiety Disorder	High cholesterol	Family mourning
FMD3	F	31	Gait disorder	Pain, Fatigue	Acute	None	None	Intense work-related stress
FMD4	M	69	Dystonia	None	Acute	None	None	Undisclosed “psychological trauma”
FMD5	M	27	Gait disorder	Pain, Fatigue	Acute	None	None	None
FMD6	F	67	Weakness	Fatigue, Cognitive difficulties	Acute	None	None	None
FMD7	M	39	Gait disorder	Pain, Fatigue	Acute	None	Gastritis	Intense family quarrel linked to the patient's desire to move abroad
FMD8	F	54	Lower limbs dystonia	Fain, Fatigue, Headache	Acute	None	Suspect of fybromyalgia, hypertension	Fall on ice
FMD9	M	63	Gait disorder	Cognitive difficulties	Subacute	None	Ashtma	None
FMD10	F	52	Right lower limb weakness	Fatigue, Sleep difficulties, Headache	Acute	Major Depressive Disorder	None	Sexual abuse
FMD11 (excluded)	F	39	Right weakness	NA	NA	NA	NA	NA
FMD12	F	61	Weakness	Pain, Fatigue	Acute	None	None	Surgery for cervical hernia
FMD13	F	42	Upper limb tremor	Fatigue, Headache, Cognitive difficulties	Subacute	OC Personality Disorder	None	Undisclosed physical trauma

Abbreviations: FMD = Functional Movement Disorders; F = Female; M = Male; NA = Not Applicable; OCD = Obsessive-Compulsive.

Table 2 – Psychometric assessment.

	HC	FMD	IBS	χ or F (df)	*p*	eta2	HC vs FMD	HC vs IBS	FMD vs IBS
Age	41.33 (16.1)	50,58 (14,56)	38.3 (15.17)	1.995 (2, 34)	.152	.105	NA	NA	NA
Sex (M/F)	8/7	5/7	3/7	1.349 (2)	.504	NA	NA	NA	NA
BMI	22.65 (3.27)	24.75 (3.84)	22.65 (3.19)	1.441 (2, 31)	.252	.085	NA	NA	NA
Handedness	.44 (.7)	.5 (.51)	.47 (.6)	.03 (2, 34)	.970	.002	NA	NA	NA
BDI-II	4.25 (3.67)	19.09 (11.21)	13.2 (8.8)	11.479 (2, 33)	**< .001**	.410	**< .001**	**.032**	.275
BAI	2.5 (2.94)	20.09 (11.02)	16.4 (13.45)	11.244	**< .001**	.405	**< .001**	**.005**	1
TAS-20 TS	36.92 (5.76)	48.09 (10.6)	49.7 (12.55)	5.69 (2, 30)	**.008**	.275	**.032**	**.015**	1
TAS-20 DIF	11.33 (3.39)	16.73 (6.94)	17.1 (6.12)	3.771 (2, 30)	**.035**	.201	.085	.069	1
TAS-20 DDF	10.75 (2.56)	12.18 (4.98)	13.8 (2.97)	1.906 (2, 30)	.116	.113	NA	NA	NA
TAS-20 EOT	14.83 (3.35)	19.18. (5.17)	18.8 (5.27)	3.121 (2, 30)	.059	.172	NA	NA	NA
DES TS	6.52 (5.93)	20.91 (16.29)	10.43 (8.22)	5.137 (2, 30)	**.012**	.255	**.012**	1	.113
DES DA	3.8 (4.53)	11,62 (11,82)	5.33 (6.91)	2.814 (2, 30)	.076	.158	NA	NA	NA
DES DF	10.62 (10.1)	30,98 (23,24)	17.83 (14.11)	4.375 (2, 30)	**.022**	.226	**.019**	.960	.242
DES DD	2.97 (3.07)	15,58 (23,18)	4.29 (4.42)	2.833 (2, 30)	.075	.159	NA	NA	NA
SoPA	30.33 (3.31)	27.18 (8.9)	30.7 (4.74)	1.097 (2, 30)	.347	.068	NA	NA	NA
SoNA	7.42 (1.93)	12.27 (5.04)	9.7 (4.67)	4.133 (2, 30)	**.026**	.216	**.022**	.593	.468

Abbreviations: BAI = Beck Anxiety Inventory; BDI-II = Beck Depression Inventory Second Version; DES = Dissociative Experience Scale (DA = Dissociative Amnesia; DF = Dissociative Functioning; DD = Depersonalization and Derealization); df = degrees of freedom; FMD = Functional Movement Disorders; F = Female; HC = Healthy Controls; IBS = Irritable Bowel Syndrome; M = Male; SD = Standard Deviation; SoNA = Sense of Negative Agency: SoPA = Sense of Positive Agency; TAS-20 = Toronto Alexithymia Scale 20 Items (DIF = Difficulty Identifying Feelings; DDF = Difficulty Describing Feelings; EOT = Externally-Oriented Thinking).

Table 3 – Mirror box illusion—embodiment questionnaire.

		Embodiment	Ownership	Agency	Location
Synchronous, mean (SD)	HC	.40 (.64)	.46 (.96)	.05 (.93)	.55 (1.11)
	FMD	.55 (.44)	.70 (.91)	.20 (1.39)	.54 (.73)
	IBS	.54 (.54)	.61 (.86)	.16 (1.29)	.67 (.90)
Asynchronous, mean (SD)	HC	.06 (.48)	.13 (.81)	−.06 (1.28)	.02 (.79)
	FMD	−.08 (.51)	−.11 (.65)	−.96 (1.09)	.55 (1.04)
	IBS	−.12 (.52)	−.33 (.94)	−.41 (.85)	.43 (.75)
Random, mean (SD)	HC	−.35 (.76)	−.33 (1.08)	−1.00 (.90)	.06 (.76)
	FMD	−.35 (.47)	−.50 (.71)	−.64 (.72)	.08 (.94)
	IBS	−.38 (.51)	−.50 (1.02)	−.91 (.97)	.23 (.90)
Group		$F(2, 34) = .204$	$F(2, 34) = .28$	$F(2, 34) = .156$	$F(2, 34) = .448$
		$P = .817$, $\eta_p 2 = .012$	$P = .758$, $\eta p2 = .016$	$P = .956$, $\eta p2 = .009$	$P = .643$, $\eta p2 = .026$
Condition		$F(2, 68) = 6.766$	$F(2, 68) = 12.744$	$F(2, 68) = 7.669$	$F(2, 68) = 3.611$
		$P < .001$, $\eta_p^2 = 305$	$P < .001$, $\eta p2 = .273$	$P < .001$, $\eta p2 = .184$	$P = .032$, $\eta p2 = .096$
Condition:	Synch vs Asynch	**.003**	**.004**	.084	.420
Post hoc	Synch vs Random	**< .001**	**<.001**	**.002**	**.039**
Comparisons	Random vs Asynch	.156	.266	.360	.699
Group * Condition		$F(4, 68) = .221$	$F(4, 68) = .477$	$F(4, 68) = 1.334$	$F(4, 68) = .561$
		$P = .926$, $\eta p2 = .013$	$P = .753$, $\eta p2 = .027$	$P = .266$, $\eta p2 = .073$	$P = .692$, $\eta p2 = .032$

Abbreviations: Asynch = Asynchronous; FMD = Functional Movement Disorders; HC = Healthy Controls; IBS = Irritable Bowel Syndrome; SD = Standard Deviation; Synch = Synchronous.

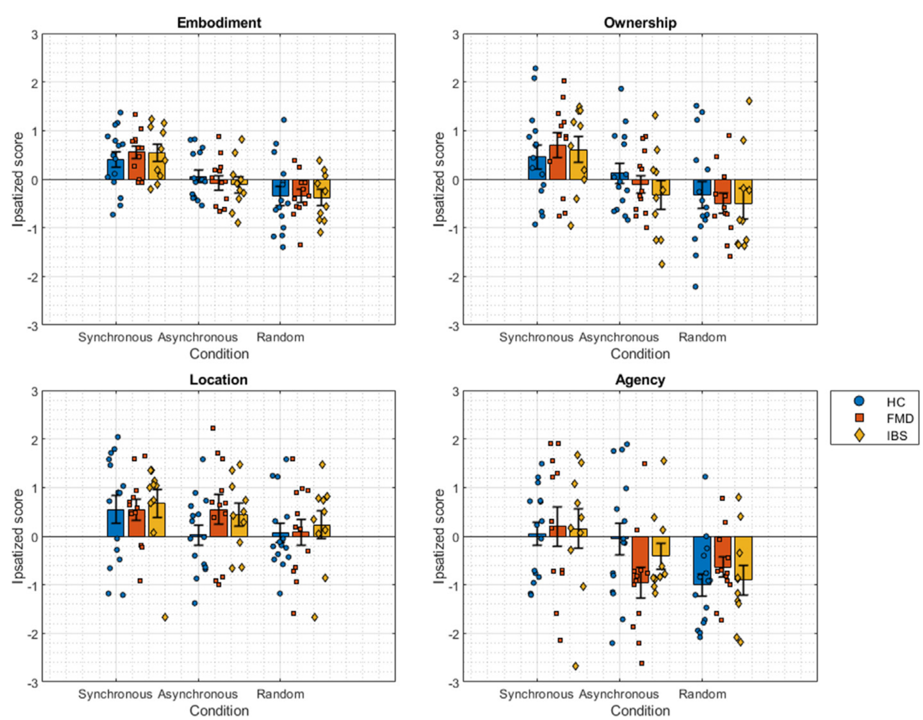

Fig. 2 – Embodiment Questionnaire Results (Total Score "Embodiment" and its subscale "Ownership", "Agency" and "Location"). Abbreviations: FMD = Functional Movement Disorders patients, represented in red squares; HC = Healthy Controls, represented in blue circles; IBS = Irritable Bowel Syndrome patients, represented in yellow diamonds. Bars represent standard error.

average bisection point of the 1.4% after the MB training in the Asynchronous condition only ($P = .003$): before training they pointed at the 76.3% of their forearm [95% C.I.: .74; .79] while after the Asynchronous training at the 77.7% of their forearm [95% C.I.: .75; .80]; this significant result was not present in the HC group, nor in the IBS group.

Such higher-order interaction (Group × Time × Condition) indicate that the effects of one factor depend on the specific levels of other factors; hence, main effects (e.g., Group, Time, Condition) and lower-order interactions (e.g., Group × Time, Group × Condition) in isolation are here reported for clarity, but should be interpreted in the specific context of the second-

Table 4 – Mirror box illusion—forearm bisection task.

Fixed effects					
			F(df)	P	Post Hoc
Intercept			9056.64 (1, 37.42)	<.001	NA
Group			15.52 (2, 37.50)	**<.001**	**FMD > HC (P < .002)** **FMD > IBS (P < .001)** HC = IBS (P = 1)
Time			.22 (1, 2284.90)	.639	NA
Condition			3.233 (2, 2284.90)	**.040**	Synch = Asynch (P = 1) Synch = Random (P = .077) Random = Asynch (P = .09)
Group × Time			5.91 (2, 2284.98)	**.003**	See below
Group × Condition			8.66 (4, 2284.98)	**<.001**	See below
Time × Condition			5.4 (2, 2284.90)	**.005**	See below
Group × Time × Condition			2.76 (4, 2284.98)	**.026**	See below
Estimated marginal means					
Group	**Condition**	**Time**	**B**	**St.Err (df)**	**[95% C.I.]**
HC	Synchronous	Pre	.692	.011 (42.796)	[.67; .71]
		Post	.674	.011 (43.243)	[.65; .70]
	Asynchronous	Pre	.670	.011 (43.243)	[.65; .69]
		Post	.678	.011 (43.243)	[.66; .70]
	Random	Pre	.677	.011 (43.274)	[.65; .70]
		Post	.672	.011 (43.243)	[.65; .69]
FMD	Synchronous	Pre	.758	.014 (40.712)	[.73; .79]
		Post	.762	.014 (40.712)	[.73; .79]
	Asynchronous	Pre	.763	.014 (40.712)	[.74; .79]
		Post	.777	.014 (40.712)	[.75; .80]
	Random	Pre	.773	.014 (40.712)	[.75; .80]
		Post	.773	.014 (40.712)	[.75; .80]
IBS	Synchronous	Pre	.682	.015 (40.712)	[.65; .71]
		Post	.684	.015 (40.712)	[.65; .71]
	Asynchronous	Pre	.682	.015 (40.712)	[.65; .71]
		Post	.683	.015 (40.712)	[.65; .71]
	Random	Pre	.690	.015 (40.712)	[.66; .72]
		Post	.691	.015 (40.712)	[.66; .72]
Pairwise Comparisons bonferroni-corrected					
Group	**Condition**		**Post - pre (shift)**	**St.Err (df)**	**P [95% C.I.]**
HC	Synchronous		**−.018**	**(.004, 2290.4)**	**P < .001 [-.026; -.011]**
	Asynchronous		.007	(.004, 2284.4)	P = .056 [.000; .015]
	Random		−.005	(.004, 2284.4)	P = .160 [-.013; .002]
FMD	Synchronous		.004	(.005, 2284.4)	P = .391 [-.005; .013]
	Asynchronous		**.014**	(.005, 2284.4)	**P = .003 [.005; .023]**
	Random		.001	(.005, 2284.4)	P = .897 [-.008; .010]
IBS	Synchronous		.002	(.005, 2284.4)	P = .673 [-.008; .012]
	Asynchronous		.001	(.005, 2284.4)	P = .792 [-.008; .012]
	Random		.001	(.005, 2284.4)	P = .797 [-.008; .012]

Abbreviations: C.I. = Confidence interval; df = degrees of freedom; FMD = Functional Movement Disorders; HC = Healthy Controls; IBS = Irritable Bowel Syndrome; St.Err = Standard Error.

level interaction. LMM also showed: (i) a significant main effect of group (F(2, 37.50) = 15.52, P < .001), where FMD patients, overall, bisected their forearm significantly more proximally compared to HC and to IBS patients (both P < .001), and no difference emerged between HC and IBS patients; (ii) a significant main effect of Condition (F(2, 2284.90) = 3.233, P = .040), which did not survive Bonferroni post-hoc comparison; (iii) significant interaction effects Group × Time (F(2, 2284.98) = 5.91, P = .003, Group × Condition (F (4, 2284.98) = 8.66, P < .001) and Time × Condition (F(2, 2284.90) = 5.4, P = .005). Further statistical details are reported in Table 4 and Fig. 3.

Finally, no correlation emerged between the psychometric variables and the MBI-related variables (Supplementary Materials).

4. Discussion

The primary aim of this study was to explore the Sense of Ownership, Agency, and potential changes in the Body Schema in patients with FMD by testing their susceptibility to bodily illusions during active movements, and compare it to a group of HC and to a group of patients with IBS,

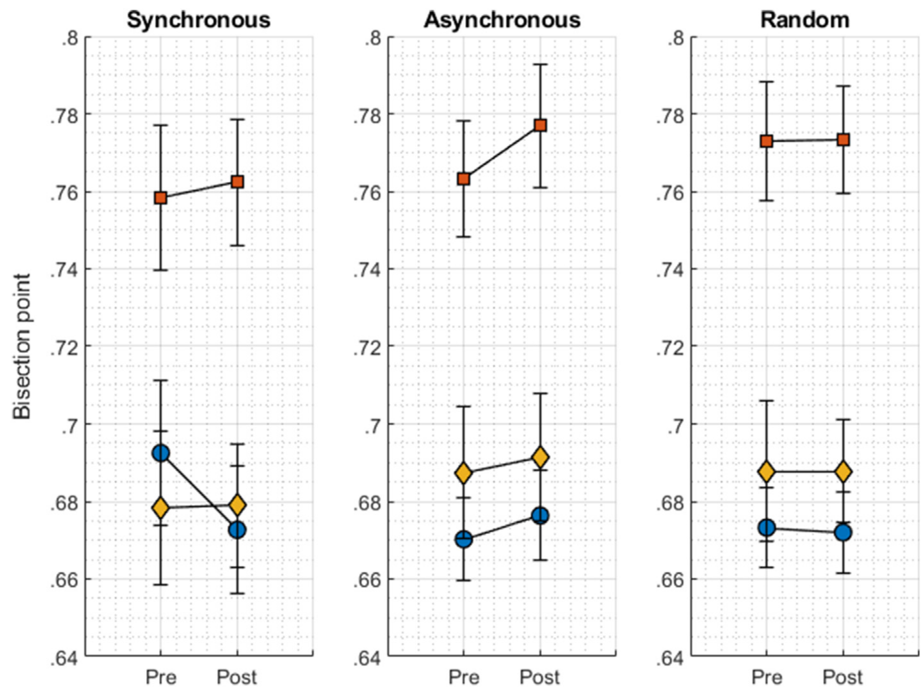

Fig. 3 – Forearm Bisection Task Results. Abbreviations: FMD = Functional Movement Disorders patient, represented in red squares s; HC = Healthy Controls, represented in blue circles; IBS = Irritable Bowel Syndrome patients, represented in yellow diamonds Bars represent standard error.

another functional disturbance affecting the gastrointestinal system.

First, we found that all groups self-reported, at the explicit level, a Sense of Embodiment of the alien hand only when visuo-motor congruency occurred. Second, at the perceptual level (i.e., Body Schema representation investigated by the Forearm Bisection Task), HC reported a distalization of their average subjective midpoint after the MBI training after the Synchronous condition only, as expected; interestingly, FMD patients not only failed to exhibit distalization under visuo-motor congruency, but instead showed a proximal shift in their average bisection point after MBI training in the Asynchronous condition. In contrast, patients with IBS showed no significant modulation of their body schema following any MB training. Moreover, FMD patients' average subjective forearm midpoint was consistently significantly higher than both HC and IBS patients' one, regardless of the MBI condition, presumably driven by their proximal bias at baseline (Fig. 3).

According to modern models of motor control, the crucial event that gives rise to self-agency is the matching process that occurs between the predicted and the actual sensory outcome (mainly visual and proprioceptive) (Seghezzi et al., 2021). In this study, we employed a variant of the classical MBI paradigm (Romano et al., 2013; Rossetti et al., 2020; Tosi et al., 2018) in which participants executed tapping movements with their dominant hand, concealed from their sight, while experimenters manipulated the visual feedback of their movement under three conditions (Synchronous, Asynchronous, Random). This paradigm allowed us to observe how the three groups (HC, FMD, and IBS) utilized the expected sensory feedback, the actual proprioceptive feedback, and the manipulated visual feedback (either congruent or incongruent with proprioception) to potentially embody an alien hand (Rossetti et al., 2020).

Using the Embodiment Questionnaire we found that, in all groups, the visuo-motor congruency (Synchronous condition) elicited higher Sense of overall Embodiment and Ownership over the alien hand with respect to both the condition of visuo-motor incongruency (Asynchronous and Random), and higher Sense of Ownership, Location (i.e., the sense that the alien hand was actually located where the participant's hand was) and Agency over the alien hand's movement with respect to the Random condition. These results replicate the finding of Rossetti et al. (2020), indicating that higher cross-modal congruency between sensory reafferent signals (i.e., coherence between the visual feedback from the alien hand and the proprioceptive feedback from the participant's hand) can evoke feelings of Embodiment for the alien hand in HC. The generation of internal predictions is thought to enable the sensorimotor system to precisely anticipate temporal and postural parameters of the movement about to be accomplished, ultimately determining self-recognition (Tsakiris et al., 2005). Hence, Rossetti et al. (2020) argued that prolonged exposure to an alien hand moving in accordance with motor predictions would lead to the embodiment of the alien hand as its own, coherently with self-generated sensory feedback. Also FMD and IBS patients reported a stronger feeling of Ownership over the alien hand in the Synchronous condition, with respect to the Asynchronous and the Random conditions. This result is in line with the findings of Demartini and colleagues (Demartini et al., 2016) about the Sense of Ownership in FMD: authors tested susceptibility of FMD patients to the RHI, and found no differences between FMD and HC at the Embodiment Questionnaire, suggesting that the explicit subjective experience of FMD patients was the one of Embodiment of the rubber hand to the same extent than HC participants. With respect to self-reported Sense of Agency, our results confirm the previous findings of Marotta and colleagues (Marotta et al., 2017), as our sample of FMD patients reported a subjective, conscious, and explicit feeling of Agency in the Synchronous condition, but not in the Asynchronous and the Random one.

Here we made a step further by investigating the proprioceptive effects of the MB training, utilizing the Forearm Bisection Task. This task measures changes in the internal representation of body metrics, and thus changes in the Body Schema. Previous studies indicate that healthy subjects tend to bisect their forearms more distally following the use of their hands or of functionally relevant tools (Sposito et al., 2012); similarly, hemiplegic patients showed a distal shift in the perceived mid-point after performing a 10-min motor task (Tosi et al., 2018). Building upon these findings, which support the concept of a plastic Body Schema, it was hypothesized that performing a motor task in the MBI would lead to either an "extension" or a "shortening" of the forearm in the updated internal body representation, depending on whether the alien hand was embodied or not. This would manifest as a shift in the perceived midpoint of the forearm. Rossetti et al. (2020) preliminary confirmed this hypothesis, showing that HC bisected their forearm more distally after visuo-motor congruency condition in MBI. Here we confirmed the finding of Rossetti et al. (2020), in that our group of HC showed a distalization of their average bisection point of the 1.8% after the MB training under visuo-motor congruency only: in other words, they manifested the hypothesized elongation of their forearm in their Body Schema after falling the bodily illusion.

With respect to our group of patients with FMD and IBS, several consideration should be made.

First, FMD patients consistently bisected their forearms more proximally compared to both HC and IBS patients, with this difference primarily stemming from their baseline bisection points (Fig. 2); in this matter (i.e., main effect of Group), no difference was found between IBS and HC. Second, both our group of patients with FMD and patients with IBS failed to exhibit distalization under visuo-motor congruency (Synchronous condition). This suggests that despite falling into the illusion and explicitly experiencing a Sense of Embodiment and Agency over the alien hand, as reported in the Embodiment questionnaire, the bodily illusion did not alter their Body Schema in the same direction as that of HC. Reviewing functional neuroimaging findings in both FMD (Demartini et al., 2021) and IBS3 (Carson & Lehn, 2016), we recently proposed that various functional disturbances might share a common core brain alteration, and they could be differentiated by distinct epiphenomena arising from alterations in functional connectivity (FC) (Nisticò et al., 2022): FC anomalies between the amygdala and the insula could play a role in the manifestation of IBS symptoms, whereas FC anomalies between the amygdala and the motor cortices might actively contribute to the development of functional motor symptoms. This led us to hypothesize that IBS patients would not have shown alterations in the Body Schema, and would have behaved similarly to HC. Our results only partially confirm our hypothesis: despite not having such a severe alteration of the Body Schema as that of FMD, IBS patients still did not show the expected distalization of the forearm as HC did. To date, research on body representation in IBS patients has been limited, with most studies focusing on their interoceptive accuracy and visceral pain processing, known to shape body representation (Demartini et al., 2014, 2021; Stenner & Haggard, 2016; Tsakiris et al., 2005) and found to be significantly altered in IBS patients compared to HC (Tsay et al., 2015). One might argue that our embodiment task, which focuses on the movement of the arms, appears more directly suited for investigating body schema disturbances in patients with upper limb symptoms, and results could not be generalized to patients with symptoms primarily affecting other areas, such as those with lower limb or gait disturbances, or even IBS. However, it is important to note that the majority of our participants with FMD had symptoms predominantly in the lower limbs or gait disturbances, as detailed in Table 1: testing upper limb movements in patients with functional tremor, paralysis, or other upper body symptoms would likely pose practical challenges, potentially compromising the feasibility and validity of the task. To address our preliminary findings and these considerations more comprehensively, future studies are needed to clarify to what extent, and potentially in which body district, body representation alteration are present in patients with IBS, employing, for example, full-body illusions (e.g. potentially using Immersive Virtual Reality) to encompass the entire body schema.

Third, after MBI training in the Asynchronous condition, where the alien hand moves at the same pace of the participant's hand but in the opposite direction, only FMD patients bisected their forearm significant more proximally than their baseline; this can be interpreted as a "shortening" of the limb representation, which is of particular relevance given that their Body Schema is altered in this same direction at resting state (Nisticò et al., 2024). In the attempt to explain FMD pathophysiology, it was proposed (Demartini et al., 2021; Stenner & Haggard, 2016) that precipitating physical events, such as physical injuries or panic attacks, are subjectively interpreted by FMD patients as indicative of a loss of control; this perception would lead to a heightened monitoring of actions, generating expectations of a conscious experience of control that the motor system physiologically cannot provide. In line with this theory, we might speculate that in our experiment, FMD patients closely monitored both proprioceptive and visual feedback during movement, aiming for complete alignment with their predictions. In the Synchronous condition, where visual feedback aligns with their predictions, a "status quo" is maintained: FMD patients are not compelled to update their priors, and thus, at the perceptual level, their Body Schema remains unaffected by the experimental manipulation. In the Asynchronous condition, they receive visual feedback conflicting with both predictions and proprioceptive feedback, fostering a sense of loss of control. Unlike HC, who typically update their prior expectations, FMD patients might rely even more on their altered priors, further shortening the representation of their arm in their Body Schema and ultimately neglecting their own moving hand. Hence, we might hypothesize that their altered Body Schema is the result of the constant reinforcement of the priors, which became altered following the postulated precipitating event;

as a matter of fact, in our sample, several patients reported either a psychological or a traumatic event in their anamnesis (Table 1). This would argue in favor of the hypothesis that there is a more permanent nature of FMD, underneath the variability, the fluctuation, and the "episodic" nature of the clinical presentation typical of functional motor symptoms. Indeed, neuroimaging studies on FMD patients at resting state revealed structural (Demartini et al., 2014), functional (Baek et al., 2017; Diez et al., 2019; Maurer et al., 2016; Monsa et al., 2018; Wilder-Smith et al., 2004), and neurochemical (Wegrzyk et al., 2018) alterations that are not present in HC. It remains to be investigated whether longer MBI training might impact the plasticity of the Body Schema in FMD patients, as occurs in successful physiotherapeutic interventions on hemiparetic patients.

4.1. Psychometric results

As expected, FMD and IBS patients had higher levels of depression and anxiety than HC. With respect to dissociation levels, only FMD patients scored higher than HC, with three patients also scoring above the cut-off. Moreover, our results further confirm the existing literature according to which both patients with FMD (Stenner & Haggard, 2016) and patients with IBS (Demartini et al., 2019) present higher levels of alexithymia than HC (with four FMD patients and five IBS patients also scoring above the cut-off at the TAS-20). Alexithymia is defined as a cluster of cognitive traits such as difficulty in identifying and describing one's own feelings and externally oriented thinking. The association between alexithymia and functional disorders is not new; alexithymia was originally conceptualized to describe clinical characteristics of patients with psychosomatic disorders who had difficulty engaging in insight-oriented psychotherapy (Porcelli et al., 2017), and it has continued to be studied in relation to medically unexplained symptoms (Tsakiris et al., 2005) and other psychiatric and neurological conditions (Sifneos, 1973). Alexithymia, along with interoception deficit (Deary et al., 1997; Ricciardi et al., 2016) and emotional dysregulation, might play a role in the pathophysiology of functional disorders, as the failure to correctly interpret bodily signals related to an emotion might lead a patient to misattribute these sensations to organic causes (Demartini et al., 2021; Edwards et al., 2012; Haggard, 2017; Stenner & Haggard, 2016). However, in our study, no significant association emerged between these psychometric variables and the results obtained at the MBI. Finally, at the SoAS, FMD patients exhibited significantly higher scores than HC in the Sense of Negative Agency component. This factor directly measures the feeling that one's body, mind, and environment are not within one's control, as assessed through items such as "My movements are automatic, my body simply makes them" (Tapal et al., 2017). Tapal and colleagues (Tapal et al., 2017) proposed that the SoNA may correspond to the concept of "learned helplessness", i. e, a chronic lack of control over the external environment, leading to feelings of passivity and potentially severe consequences for motivation to act (Maier & Seligman, 1976; Ricciardi et al., 2021). Our results not only align with the involuntary nature of FMD symptoms but also suggest that the observed difference in this construct compared to HC may reflect the diminished motivation and the sense of helplessness experienced by individuals with chronic FMD, especially considering the prolonged duration of living with the condition and the time spent seeking and comprehending the FMD diagnosis, a factor prognostic for recovery (Abramson et al., 1978).

5. Conclusions and future perspectives

This work shows that, at the conscious and subjective level, HC, FMD, and IBS patients were able to report feeling of embodiment over an alien hand when visuo-motor congruency occurs, confirming previous findings on the same population of FMD patients. It confirms the existing literature by revealing that, at the implicit level of the body schema representation, HC showed results coherent with their subjective experience (i.e., an "elongation" of the arm representation in the Body Schema after MBI training under visuomotor congruency). It adds to the literature by showing that: (i) FMD patients and IBS patients failed to show the same distalization, although the Body Schema alteration in IBS was not as severe as in patients with FMD; this indicates that a dissociation between the explicit and implicit sense of Ownership and Agency exist in both disturbances, and might suggest that Body Schema alterations at different degrees may exist across different functional disturbances; (ii) FMD patients showed a proximalization of their bisection point (i.e., a "shortening" of the arm representation in the Body Schema) in the Asynchronous condition, when the expected prediction and the proprioceptive feedback of the movement did not match with the visual feedback. In a predictive coding perspective, we speculated that FMD patients tended to rely even more on their altered priors, to avoid the potential sense of loss of control that might emerge in conditions where the gathered sensory information do not match.

Future research with larger samples should examine whether specific FMD phenotypes, such as those characterized by fatigue, weakness, or hyperkinetic symptoms, affect embodiment differently. These studies could also consider variations across body regions and account for the impact of comorbidities, providing a more nuanced understanding of how these factors influence body schema and task performance. Moreover, longer MBI training could be implemented to test whether it might impact the plasticity of the Body Schema, as seen in successful physiotherapeutic interventions on hemiparetic patients. Finally, further investigations, incorporating neurophysiological and neuroimaging measures, are necessary to deepen our understanding of the relationship between body representation, in its various facets, and functional symptoms across different systems.

Scientific transparency statement

DATA: No raw or processed data supporting this research are publicly available.

CODE: This research did not make use of any analysis code.

MATERIALS: All study materials supporting this research are publicly available:

DESIGN: This article reports, for all studies, how the author(s) determined all sample sizes, all data exclusions, all data inclusion and exclusion criteria, and whether inclusion and exclusion criteria were established prior to data analysis.

PRE-REGISTRATION: No part of the study procedures was pre-registered in a time-stamped, institutional registry prior to the research being conducted. No part of the analysis plans was pre-registered in a time-stamped, institutional registry prior to the research being conducted.

For full details, see the *Scientific Transparency Report* in the supplementary data to the online version of this article.

CRediT authorship contribution statement

Veronica Nisticò: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Francesca Conte:** Writing – original draft. **Ileana Rossetti:** Data curation, Formal analysis, Supervision. **Neofytos Ilia:** Writing – original draft. **Adriano Iacono:** Writing – original draft. **Giovanni Broglia:** Data curation. **Silvia Scaravaggi:** Data curation. **Claudio Sanguineti:** Data curation. **Francesco Lombardi:** Data curation. **Laura Mangiaterra:** Data curation. **Roberta Tedesco:** Data curation. **Alessia Campomori:** Data curation. **Martina Molinari:** Data curation. **Roberta Elisa Rossi:** Conceptualization. **Alessandro Repici:** Writing – review & editing, Resources. **Alberto Priori:** Writing – review & editing, Resources. **Lucia Ricciardi:** Writing – review & editing, Conceptualization. **Francesca Morgante:** Writing – review & editing. **Mark J. Edwards:** Writing – review & editing, Supervision. **Angelo Maravita:** Writing – review & editing, Supervision, Conceptualization. **Benedetta Demartini:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Conceptualization.

Disclosure statement

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2024.12.023

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