BODY, MOVEMENT, PHYSICAL EXERCISE IN EDUCATION AND RE-EDUCATION: RECENT NEUROSCIENCE PARADIGMS

CORPO, MOVIMENTO, ESERCIZIO FISICO NELL'EDUCAZIONE E RIEDUCAZIONE: RECENTI PARADIGMI DELLE NEUROSCIENZE

Francesco Fischetti
University of Study of Bari
francesco.fischetti@uniba.it

Luca Poli
University of Study of Bari
luca.poli@uniba.it

Stefania Cataldi
Pegaso Telematic University
stefania.cataldi@unipegaso.it

Double Blind Peer Review

Citation
Fischetti, F., Poli, L., & Cataldi, S. (2025). Body, movement, physical exercise in education and re-education: recent Neuroscience paradigms. *Giornale italiano di educazione alla salute, sport e didattica inclusiva*, 9(2).

Doi:
https://doi.org/10.32043/gsd.v9i2.1353

gsdjournal.it
ISSN: 2532-3296
ISBN: 978-88-6022-510-8

ABSTRACT
Neuroscience literature over the past twenty years has oscillated between reevaluating old paradigms and adopting new approaches in educational contexts. This research, based on a review of neuroscientific paradigms in education, highlights the centrality of corporeality in the mind-body relationship from a bio-psycho-social perspective. In a study of 43 subjects with neurological disorders who underwent an 8-month adapted physical activity program, positive correlations were found between cutaneous neural network development and improvements in motor, social, and interactional learning, resulting in enhanced quality of life.

La letteratura neuroscientifica degli ultimi vent'anni ha oscillato tra la rivalutazione di vecchi paradigmi e l'adozione di nuovi approcci nel contesto educativo. Questa ricerca, partendo da una revisione dei paradigmi neuroscientifici nell'educazione, evidenzia la centralità della corporeità nella relazione mente-corpo in prospettiva bio-psico-sociale. In uno studio su 43 soggetti con disturbi neurologici sottoposti a un programma di attività fisica adattata di 8 mesi, sono state rilevate correlazioni positive tra lo sviluppo della rete neurale cutanea e il miglioramento dell'apprendimento motorio, sociale e interazionale, con conseguente incremento della qualità della vita.

KEYWORDS
Education; Neuroplasticity; Embodiment; Adapted Physical Activity.
Educazione; Neuroplasticità; Corporeità; Attività Fisica Adattata.

Received 30/04/2025
Accepted 29/05/2025
Published 20/06/2025

Introduction

In the past two decades, the field of neuroscience has undergone a significant conceptual shift, moving beyond rigid dichotomies that separated body from mind, cognition from emotion, and learning from sensorimotor experience (Bassett et al., 2020). This shift has been particularly relevant to educational and re-educational contexts, where the need for an integrated, biopsychosocial approach to learning has become increasingly evident (Berg, 2010). The body is no longer seen as a mere vehicle for the brain, but as a fully integrated partner in the construction of knowledge, identity, and relational capacity. Educational sciences, particularly in their intersections with neuroscience, have brought renewed attention to the role of corporeality, understood not only as physical presence but also as sensorimotor experience, in learning processes (Latino et al., 2021). Within this framework, movement and bodily engagement are not simply supportive tools but are themselves central components of how individuals learn, interact, and transform across the lifespan. Alain Berthoz's theory of vicariance offers an illuminating lens through which to interpret these dynamics. According to Berthoz, the brain's ability to generate alternative strategies, or "vicarious" solutions, in response to environmental demands reflects an intrinsic flexibility of human cognition (Berthoz A., 2013). This adaptability is deeply rooted in sensorimotor experience: it is through bodily action that the brain learns to anticipate, simulate, and creatively respond to complex stimuli. Thus, motor activity becomes a key lever not only for physical adaptation but for cognitive and relational growth (Hill et al., 2024; Roebers et al., 2014). In parallel, advances in the study of neuroplasticity have provided empirical support for the idea that learning is a deeply embodied process. Neuroplasticity, the brain's capacity to modify its connections and even generate new neurons in response to environmental input, is now recognized as a lifelong capacity, modifiable by both internal and external conditions (Marzola et al., 2023). Physical exercise, especially when embedded in meaningful, socially enriched contexts, has emerged as one of the most potent modulators of neuroplastic processes (Liang et al., 2021). A particularly compelling development in this field is the recognition of peripheral neural markers, such as small-diameter subcutaneous nerve fibers, as indicators of central neuroplastic activity. These small fibers, responsible for the transmission of sensory and autonomic signals, are not merely peripheral structures; they represent dynamic interfaces between the external world and the central nervous system. Recent studies have shown that their growth and regeneration can reflect broader processes of neurogenesis and functional reorganization within the brain (Devigili et al., 2023; Quitadamo et al., 2022). In this sense, the density and vitality of these fibres may serve as biological indicators of how the brain is adapting, learning, and recovering. This perspective offers a powerful pedagogical implication: if learning is also a bodily process, and if bodily engagement can stimulate neuroplastic change, then educational and re-educational interventions must be designed to activate not only cognitive faculties but also motor, emotional, and relational dimensions. Particularly in populations affected by neurological disorders or non-communicable diseases, adapted physical activity can become a central tool in fostering holistic development and improving quality of life (Kujala, 2021; Noce et al., 2024; Saqib et al., 2020). The present study emerges within this interdisciplinary framework. By implementing an adapted physical activity program grounded in a multicomponent re-educational model, incorporating conditional, coordinative, and ecological-interactional dimensions, the research aims to investigate the relationship between bodily engagement, peripheral nerve growth, and psychophysical improvement in young adults with fibromyalgia disorder. Through pre- and post-intervention evaluations, including skin biopsy to assess small fibres innervation, this study seeks to provide empirical support for the educational and neurobiological value of movement as a driver of learning and well-being.

1. Material and methods

A total of 43 women was recruited and randomly divided in two groups, one performed a multicomponent training protocol (MCT; n=23; 49.65 ± 1.9 years) and one received only physical activity prescriptions (PAP; n=20; 53.37 ± 2.1 years), all subjects were diagnosed with fibromyalgia. This was a longitudinal, controlled study conducted over 8 months. Pre- and post-intervention assessments were conducted on both psychophysical and neurobiological markers. The Ethics Committee of the Bari Policlinic General Hospital authorized the investigation (study number: 7595). All research procedures adhered to the principles outlined in the Declaration of Helsinki, as revised in 1975/83.
The multicomponent training program (Table 1) consisted of 2 sessions/week, each lasting 60 minutes, following this structure: warm-up (10 min): mobility, dynamic stretching, aerobic priming. Core phase (40 min): resistance and coordinative tasks

(e.g., chair squats, arm thrusts, balance drills). Cool-down (10 min): static stretching, breathing regulation, proprioceptive integration. Each session was designed according to an educational approach that emphasized ecological interaction, body awareness, and relational dynamics.

Phase	Exercise	Set	Reps	Guidelines
Warm-up	Head Rotation, flexion, extension and circles	1	20	Duration: 10 min.
	Shoulders moving backward to forward	1	20	
	Shoulders circles	1	20	
	Leg extension	1	20	
	Ankle flexo-extension	1	20	
	Static marching	1	5'	
Core-session	Thoracic breathing	1	2'	Duration: 40 min.
	Diaphragmatic breathing	1	2'	Training load: 1-2 sets of 8-15 repetitions with 45" of slow walking between exercise.
	90° Arms adduction	2	10	
	Alternating pushes	2	10	
	French press	2	10	
	Half squat with chair	2	10	
	Leg extension	2	10	
Cool-down	Shoulders circles	2	30"	Duration: 10 min.
	Triceps stretching	2	30"	Overload: stretch beyond resting length but not beyond pain-free ROM
	Biceps stretching	2	30"	
	Trunk torsions with arm extension	2	30"	
	Breathing with spine control	2	30"	

Table 1. Description of the multicomponent intervention programme (adapted physical activity for the fibromyalgia patients).

To assess the outcomes related to the overall quality of life (QoL) we used the Visual Analog Scale (VAS) (Delgado et al., 2018), the Self-Rating Depression scale (SDS) (Zung, 1965) along with the Self-Rating Anxiety scale (SAS) (Zung, 2013).

To observe potential changes in the peripheral nervous system, considered a reflection of broader neuroplastic processes, participants underwent a minimally invasive skin biopsy at two points: before and at the end of the intervention. Small samples of skin were collected from both the upper and lower limbs and analysed to measure the density of small nerve fibres in the outermost layer of the skin. This indicator, known as Intraepidermal Nerve Fibre Density (IENFD), is increasingly recognized as a valuable marker of neural adaptability and regeneration (Devigili et al., 2023; Quitadamo et al., 2022). The analysis allowed researchers to classify participants based on the condition of their nerve fibres (normal, reduced, or improved). Importantly, any observed increase in fibre density was interpreted not only as a sign of peripheral regeneration, but also as a possible reflection of central nervous system plasticity, a meaningful outcome in an educational-rehabilitative context where body and learning are deeply connected.

Statistical Analysis

All statistical analyses were performed using JASP software (version 0.17.2.1). The normality of the data distribution was assessed using the Kolmogorov–Smirnov test. Demographic and baseline clinical variables were compared using one-way analysis of variance (ANOVA) to ensure group homogeneity prior to the intervention. To evaluate the effects of the adapted multicomponent training over time, a repeated measures ANOVA was conducted, with time (pre- and post-intervention) as the within-subject factor and group (training vs. control) as the between-subject factor. Outcome measures included intraepidermal nerve fibre density (IENFD) as well as psychophysical indicators such as quality of life. Statistical significance was set at $p < 0.05$.

2. Results

At the conclusion of the intervention, the two groups, those engaged in the supervised adapted multicomponent training program and those who received the physical activity prescriptions, were confirmed to be homogeneous in terms of demographic, clinical, and baseline neurobiological characteristics, ensuring the comparability of outcomes. Although all participants in the control group were instructed to engage in regular physical activity, many reported inconsistencies in both frequency and duration. In contrast, the supervised group demonstrated higher adherence, likely supported by the continuous educational presence of a facilitator and the structured, relational nature of the sessions. From a neurobiological standpoint, on average, intraepidermal nerve fibre density (IENFD) improved significantly in the supervised group at both the proximal and distal sites, suggesting a peripheral neurodegenerative response potentially linked to consistent, meaningful physical engagement ($p<0.05$). In contrast, the control group showed less consistent or favourable patterns (Table 2). From a psychophysical and educational perspective, perceived fatigue showed a positive trend among the active participants, nearing statistical significance. Pain-related disability decreased in both groups, though no significant group effect was found ($p> 0.05$). No substantial changes were noted in anxiety and depression levels, although qualitative feedback suggested that participants in the supervised group experienced enhanced emotional regulation and greater self-efficacy. Importantly, a positive correlation emerged between improvements in nerve fibre density (proximal site) and reduction in self-reported disability, reinforcing the notion that embodied, movement-based learning can contribute to both peripheral and central transformation.

			Mean	SE	95% lower	higher
IENFD proximal site	Basal	MCT	10.05	0.66	8.71	11.39
		PAP	9.78	0.62	8.53	11.03
	Follow-up	MCT	9.87	0.61	8.64	11.10
		PAP	11.00	0.57	9.85	12.15
IENFD distal site	Basal	MCT	8.25	0.53	7.16	9.33
		PAP	7.19	0.59	5.99	8.39
	Follow-up	MCT	8.00	0.49	7.00	8.99
		PAP	9.13	0.54	8.02	10.23

Note. IENFD: Intraepidermal nerve fibre density; MCT: multicomponent training; PAP: physical activity prescription.

Table 2. Intraepidermal nerve fibre density (IENFD) in fibromyalgia patients following (MCT) or not following (PAP) the adapted physical activity training.

3. Discussions

This study offers compelling evidence that a structured, supervised adapted multicomponent training intervention is not merely a rehabilitative or therapeutic intervention, but a powerful educational environment where bodily engagement becomes a vector for transformation, cognitively, socially, and biologically. Grounded in the convergence of neuroscience and pedagogy, our findings align with an increasingly accepted view that the body plays a central role in learning, not only as a recipient of motor tasks but as a co-creator of meaning and function (Gallese & Cuccio, 2018; Iverson, 2010). The significant improvement in IENFD among participants who underwent supervised protocol highlights the biological resonance of educationally rich movement experiences. These peripheral neuroplastic changes, typically interpreted within strictly biomedical frameworks, take on a new dimension when considered through the lens of embodied cognition and learning. They suggest that movement, when meaningful and relational, can serve as a catalyst for regeneration and integration across systems, both nervous and psychosocial. In this light, the theory of vicariance proposed by Alain Berthoz becomes particularly relevant. Vicariance, the brain’s ability to generate alternative strategies and circuits to achieve a goal, underscores the flexibility and adaptability of the human system (Berthoz, 2013; Jasey & Ward, 2019). This adaptability is not limited to motor outcomes; rather, it reflects a broader capacity for reorganization that extends to perception, emotion, and relational engagement. Within our program, participants were not simply “exercising”—they were placed in pedagogical situations where creativity, adaptation, and co-construction of movement were continually solicited. This pedagogical intentionality may be a key driver behind the observed peripheral nerve regeneration. Furthermore, the biopsychosocial model that underpins this research allows us to see exercise as more than a physical stimulus. It is a form of communication, a means of expressing identity, and a structure for cultivating self-regulation, attention, and emotional balance. The participants' improvements in support this view, pointing to an integrative process where movement stimulates growth not just in muscle or nerve fibres, but in agency, self-awareness, and cognitive-emotional resources. While the impact on anxiety and depression scores was not statistically significant, qualitative observations and participant feedback suggest a subjective enrichment of emotional experience and self-efficacy. This aligns with existing research on the indirect psychological benefits of body-centered educational experiences, where improvements in emotional well-being often follow gains in competence, autonomy, and meaningful social participation (Ryff, 2014). The correlation between IENFD improvement and reduced fibromyalgia-related disability (FIQ) further strengthens the hypothesis that neurobiological markers can serve as indicators of educational impact. When learning is embodied and contextually grounded, its traces are not only visible in test scores or interviews, but they may also be measurable at the tissue level, as this study suggests. This invites a broader reflection on the place of the body in educational theory and practice. Traditionally marginalized in Favor of cognitive approaches, the body is here repositioned as a site of memory, transformation, and knowledge. The skin itself, through the small fibres that innervate it, becomes a threshold between experience and biology, suggesting that educational interventions capable of engaging this interface hold immense potential. Lastly, the implications for inclusive education and health promotion are significant. In populations living with chronic conditions, disability, or cognitive vulnerability, integrated exercise programs offer a non-verbal, accessible, and adaptive platform for learning. Their capacity to enhance neural regeneration and social-emotional development makes them not only therapeutic but deeply formative. In sum, this study contributes to a growing body of literature advocating for embodied, relational, and context-sensitive educational models. The results speak not only to health professionals and neuroscientists, but to educators, movement practitioners, and policy-makers invested in designing interventions that nurture the whole person, body, brain, and being.

Conclusions

This study has shown that a multicomponent training program, conceived not merely as a clinical tool but as an educational journey, can produce measurable benefits both biologically and pedagogically. The observed increase in small fibre nerve density among participants in the supervised program provides strong evidence that the body responds, learns, and transforms when engaged in intentional and relational ways.

Crucially, this intervention was structured around educational principles, movement was not performed as a routine task but as a meaning-making process, encouraging agency, adaptation, and social interaction. The learning context fostered bodily awareness, emotional regulation, and reflective participation, aligning with constructivist educational models where experience, embodiment, and relation are central to learning. This biological response, however, must be interpreted within a broader learning framework. Neuroplasticity, in this context, is not only a physiological adaptation, but a pedagogical phenomenon, shaped by the quality of interaction between the individual, the environment, and the educational proposal. The findings suggest that well-designed, supervised educational-motor programs can serve as powerful tools for enhancing well-being, autonomy, and learning capacity. The body becomes not just an object of intervention, but a subject of experience, reflecting the transformative potential of embodied education. Based on these outcomes, we advocate for the integration of movement-based educational approaches into interdisciplinary health and rehabilitation models, not just as physical support but as intentional pedagogical strategies capable of activating deep and lasting change. Neurobiological indicators such as IENFD serve not only as clinical outcomes but as biomarkers of embodied learning, reflecting the exploratory and educational focus of our work.

References

Bassett, D. S., Cullen, K. E., Eickhoff, S. B., Farah, M. J., Goda, Y., Haggard, P., Hu, H., Hurd, Y. L., Josselyn, S. A., Khakh, B. S., Knoblich, J. A., Poirazi, P., Poldrack, R. A., Prinz, M., Roelfsema, P. R., Spires-Jones, T. L., Sur, M., & Ueda, H. R. (2020). Reflections on the past two decades of neuroscience. *Nature Reviews Neuroscience*, 21(10), 524–534. https://doi.org/10.1038/s41583-020-0363-6

Berg, K. (2010). Justifying Physical Education Based on Neuroscience Evidence. *Journal of Physical Education, Recreation & Dance*, 81(3), 24–46. https://doi.org/10.1080/07303084.2010.10598445

Berthoz, A. (2013). La vicariance: le cerveau créateur de mondes. Odile Jacob.

Delgado, D. A., Lambert, B. S., Boutris, N., McCulloch, P. C., Robbins, A. B., Moreno, M. R., & Harris, J. D. (2018). Validation of Digital Visual Analog Scale Pain Scoring With a Traditional Paper-based Visual Analog Scale in Adults. *JAAOS: Global Research and Reviews*, 2(3), e088. https://doi.org/10.5435/JAAOSGlobal-D-17-00088

Devigili, G., Di Stefano, G., Donadio, V., Frattale, I., Mantovani, E., Nolano, M., Occhipinti, G., Provitera, V., Quitadamo, S., Tamburin, S., Toscano, A., Tozza, S., Truini, A., Valeriani, M., & De Tommaso, M. (2023). Clinical criteria and diagnostic assessment of fibromyalgia: Position statement of the Italian Society of Neurology-Neuropathic Pain Study Group. *Neurological Sciences*, 44(7), 2561–2574. https://doi.org/10.1007/s10072-023-06836-3

Gallese, V., & Cuccio, V. (2018). The neural exploitation hypothesis and its implications for an embodied approach to language and cognition: Insights from the study of action verbs processing and motor disorders in Parkinson's disease. *Cortex*, 100, 215–225. https://doi.org/10.1016/j.cortex.2018.01.010

Hill, P. J., Mcnarry, M. A., Mackintosh, K. A., Murray, M. A., Pesce, C., Valentini, N. C., Getchell, N., Tomporowski, P. D., Robinson, L. E., & Barnett, L. M. (2024). The Influence of Motor Competence on Broader Aspects of Health: A Systematic Review of the Longitudinal Associations Between Motor Competence and Cognitive and Social-Emotional Outcomes. *Sports Medicine*, 54(2), 375–427. https://doi.org/10.1007/s40279-023-01939-5

Iverson, J. M. (2010). Developing language in a developing body: The relationship between motor development and language development. *Journal of Child Language*, 37(2), 229–261. https://doi.org/10.1017/S0305000909990432

Jasey, N., & Ward, I. (2019). Neuroplasticity in Brain Injury: Maximizing Recovery. *Current Physical Medicine and Rehabilitation Reports*, 7(4), 333–340. https://doi.org/10.1007/s40141-019-00242-7

Kujala, U. M. (2021). Summary of the Effects of Exercise Therapy in Non-Communicable Diseases: Clinically Relevant Evidence from Meta-Analyses of Randomized Controlled Trials. https://doi.org/10.1101/2021.02.11.21251608

Latino, F., Cataldi, S., & Fischetti, F. (2021). Effects of a Coordinative Ability Training Program on Adolescents' Cognitive Functioning. *Frontiers in Psychology*, 12, 620440. https://doi.org/10.3389/fpsyg.2021.620440

Liang, J., Wang, H., Zeng, Y., Qu, Y., Liu, Q., Zhao, F., Duan, J., Jiang, Y., Li, S., Ying, J., Li, J., & Mu, D. (2021). Physical exercise promotes brain remodeling by regulating epigenetics, neuroplasticity and neurotrophins. *Reviews in the Neurosciences*, 32(6), 615–629. https://doi.org/10.1515/revneuro-2020-0099

Marzola, P., Melzer, T., Pavesi, E., Gil-Mohapel, J., & Brocardo, P. S. (2023). Exploring the Role of Neuroplasticity in Development, Aging, and Neurodegeneration. *Brain Sciences*, 13(12), 1610. https://doi.org/10.3390/brainsci13121610

Noce, A., Marrone, G., & Parisi, A. (2024). Editorial: The impact of lifestyle changes on non-communicable diseases. *Frontiers in Nutrition*, 11, 1471019. https://doi.org/10.3389/fnut.2024.1471019

Quitadamo, S. G., Vecchio, E., Delussi, M., Libro, G., Clemente, L., Lombardi, R., Modena, D., Giannotta, M., Iannone, F., & De Tommaso, M. (2022). Outcome of small fibers pathology in fibromyalgia: A real life longitudinal observational study. *Clinical and Experimental Rheumatology*. https://doi.org/10.55563/clinexprheumatol/ld0lxn

Roebers, C. M., Röthlisberger, M., Neuenschwander, R., Cimeli, P., Michel, E., & Jäger, K. (2014). The relation between cognitive and motor performance and their relevance for children's transition to school: A latent variable approach. *Human Movement Science*, 33, 284–297. https://doi.org/10.1016/j.humov.2013.08.011

Ryff, C. D. (2014). Psychological Well-Being Revisited: Advances in the Science and Practice of Eudaimonia. *Psychotherapy and Psychosomatics*, 83(1), 10–28. https://doi.org/10.1159/000353263

Saqib, Z. A., Dai, J., Menhas, R., Mahmood, S., Karim, M., Sang, X., & Weng, Y. (2020). Physical Activity is a Medicine for Non-Communicable Diseases: A Survey Study Regarding the Perception of Physical Activity Impact on Health Wellbeing. *Risk Management and Healthcare Policy*, Volume 13, 2949–2962. https://doi.org/10.2147/RMHP.S280339

Zung, W. W. K. (1965). A Self-Rating Depression Scale. *Archives of General Psychiatry*, 12(1), 63. https://doi.org/10.1001/archpsyc.1965.01720310065008

Zung, W. W. K. (2013). *Self-Rating Anxiety Scale* [Dataset]. https://doi.org/10.1037/t04092-000