BODY VISUALIZATION AND VIRTUAL REALITY: AN ENACTIVE-TECHNOLOGICAL APPROACH TO MOTOR LEARNING IN KINESIOLOGY

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ABSTRACT
Through a critical analysis of the transition from cognitivist models to enactive-ecological approaches, the paper argues that virtual reality enables the construction of learning environments consistent with the principles of embodied cognition. Immersive technologies may provide multisensory real-time information, support adaptive motor organization, and facilitate the emergence of motor patterns through the dynamic interaction between organism and environment. Particular attention is devoted to the role of immersive systems in promoting situated learning processes, perceptual-motor regulation, and functional adaptation within rehabilitation and educational contexts. Immersive virtual reality technologies should not be considered merely as technical instructional tools, but rather as methodological extensions of the enactive approach to motor learning. Their relevance lies in the possibility of integrating perception, embodiment, action, and situated experience within adaptive environments capable of supporting meaningful motor learning and functional reorganization in kinesiological settings.

KEYWORDS
Kinesiology; virtual reality; embodied cognition; enactive approach; motor learning.

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1. Introduction

Contemporary kinesiology is progressively moving beyond a purely biomechanical conception of movement toward embodied and enactive perspectives. Although biomechanics remains essential for movement analysis, it cannot fully explain the perceptual, adaptive, and experiential dimensions through which individuals organize action (Winter, 2009; Seifert et al., 2013). In this perspective, the body is understood not only as a mechanical structure, but also as a lived and situated experience (Merleau-Ponty, 1945; Gallagher, 2005). Enactive and ecological approaches interpret cognition as an embodied process emerging from the dynamic interaction between organism and environment (Varela et al., 1991; Thompson, 2007). Consequently, motor learning should be understood as an adaptive process shaped by sensory feedback, contextual variability, and bodily experience (Davids et al., 2008; Araújo et al., 2006). Within this framework, body visualization and immersive virtual reality represent methodological tools capable of supporting motor regulation, bodily awareness, and adaptive learning processes (Jeannerod, 2001; Munzert et al., 2009; Ladda et al., 2021). VR environments, in particular, may provide real-time feedback, task modulation, and perceptual immersion consistent with the principles of embodied cognition and motor learning (Darekar, 2023). The aim of this article is therefore to examine the convergence between body visualization and immersive virtual reality within the enactive approach to contemporary kinesiology.

2. From the Biomechanical Paradigm to the Lived Body: Epistemological Foundations

Since the second half of the twentieth century, the biomechanical approach has represented the methodological foundation of movement sciences. It has made it possible to describe, measure, and optimize motor gestures through quantifiable parameters such as forces, levers, joint angles, velocities, and accelerations. This perspective, rooted in the principles of Newtonian physics and in the Cartesian conception of the body as res extensa, has generated valuable knowledge for sports training, biomedicine, and ergonomics (Winter, 2009). Nevertheless, the biomechanical model presents structural limitations when it comes to understanding human movement in its experiential, intentional, and adaptive dimensions. Reducing the body to a mechanical system neglects the lived dimension of movement, namely the way individuals perceive, assign meaning to, and organize their bodily actions in relation to goals and contexts (Terzuolo & Viviani, 2010; Seifert et al., 2013). The critique of mechanistic reductionism finds theoretical foundations in Maurice Merleau-Ponty's phenomenology of the body. In Phénoménologie de la perception (1945), Merleau-Ponty distinguishes between the body-object (*Körper*), understood as a measurable physical entity, and the lived body (*Leib*), namely the body as the subjective pole of experience and the original locus of perception and motor intentionality. For Merleau-Ponty, the lived body is not merely an instrument of consciousness; rather, it is consciousness itself insofar as it is embodied: "The body is our general medium for having a world" (Merleau-Ponty, 1945, p. 147). This means that movement cannot be reduced to a sum of mechanical components, but emerges as a meaningful gesture situated within a perceptual-motor horizon that anticipates and structures action. The lived body therefore constitutes the pre-reflective foundation of

our relationship with space, objects, and others (Carman, 1999; Gallagher, 2005). This phenomenological perspective finds a rigorous epistemological articulation in the enactive approach introduced by Francisco Varela, Evan Thompson, and Eleanor Rosch in "The Embodied Mind" (1991). Enactivism opposes classical cognitivism, which conceives the mind as a computational system processing symbolic representations of the external world. In contrast, enactivism argues that cognition is embodied, situated, and enacted: meaning does not pre-exist in the world, but emerges through the dynamic interaction between organism and environment (Varela et al., 1991; Thompson, 2007). From this perspective, perception and action are not sequential processes but co-constitutive dimensions: to perceive already means to act, and to act already means to perceive. The nervous system does not represent the world; rather, it generates neural activation patterns that guide action in an adaptive and situated manner (Di Paolo et al., 2010; Gomez Paloma, 2013; Ceciliani, 2018). The enactive approach integrates with James Gibson's ecological theory of perception (1979), according to which perception is direct and not mediated by internal mental representations. Gibson introduced the concept of affordances, namely the functional possibilities that the environment offers to an organism in relation to its motor capacities. A stair, for example, is not merely an abstract geometric entity, but an opportunity for climbing for a subject possessing specific morphological characteristics and motor abilities. Affordances emerge from the perception-action coupling and vary according to the intentionality of the subject and the context (Gibson, 1979; Chemero, 2009). This principle has profound implications for kinesiology: movement cannot be understood as the execution of predefined motor programs, but rather as an exploratory and adaptive process that self-organizes according to the constraints of the task, the organism, and the environment (Davids et al., 2008; Araújo et al., 2006). The transition from the biomechanical paradigm to

the enactive-ecological one therefore implies a radical shift in perspective. The body is no longer conceived as a machine to be optimized, but as an autonomous system endowed with agency and capable of self-organization and meaning attribution (Maturana & Varela, 1980). Consequently, motor learning does not consist in acquiring invariant schemas, but in developing flexible and adaptive strategies emerging from situated practice and contextual variability (Renshaw et al., 2010; Chow et al., 2011). This conception finds increasing confirmation in cognitive neuroscience, which has demonstrated that motor cognition is grounded in distributed neural networks, including mirror systems integrating perception, imagination, and action (Rizzolatti & Craighero, 2004; Jeannerod, 2006). Contemporary kinesiology, therefore, cannot disregard an epistemological approach that recognizes the centrality of the lived body, embodied cognition, and the co-determination between subject and environment.

3. Polysensory Body Visualization and Motor Learning

Within contemporary kinesiology, body visualization should not be considered a secondary mental technique, but rather an embodied simulation process capable of supporting movement organization, motor regulation, and learning. According to Jeannerod motor imagery shares structural and functional properties with actual movement execution, activating neural mechanisms similar to those involved in real action. From this perspective, body visualization represents a situated and multisensory experience through which the subject anticipates, perceives, and internally organizes movement within a meaningful perceptual-motor framework. Recent studies emphasize the intrinsically multisensory nature of action imagery, showing that motor images may involve visual, kinesthetic, auditory, and proprioceptive dimensions

depending on the task, the subject's experience, and the adopted perspective (Krüger et al., 2024). The quality of imagery is also influenced by body position, ecological constraints, and prior motor practice. Consequently, body visualization should not be standardized, but designed according to the perceptual and functional characteristics of the task and to the subject's motor history. From a neuroscientific perspective, motor imagery shares neural substrates with both action observation and movement execution, involving premotor and parietal areas as well as, to a lesser extent, the primary motor cortex (Esposito et al., 2024). Neuroimaging and transcranial magnetic stimulation studies confirm that mental practice activates motor-related brain regions and may contribute to motor learning and movement preparation processes (Feitosa et al., 2022). This interpretation is coherent with the theory of embodied simulation developed by Gallese and colleagues, according to which cognition emerges through the internal simulation of actions and bodily states. The literature also suggests that imagery practice may improve motor performance when integrated into structured learning pathways and supported by appropriate sensory feedback (Gallese, 2018). Furthermore, mental practice may facilitate motor memory consolidation during sleep, similarly to physical training (Debarnot et al., 2009). These findings reinforce the idea that body visualization activates authentic perceptual-motor learning mechanisms rather than purely abstract cognitive processes. For kinesiology, this implies that body visualization should function as a situated pedagogical mediation capable of supporting anticipation, bodily awareness, motor regulation, and skill consolidation without rigidly separating cognitive and motor dimensions. In some tasks, visual-spatial imagery may be more relevant, whereas in others the kinesthetic component becomes central, particularly in movements requiring coordination, rhythm, or fine force regulation. From this perspective, body visualization also prepares the transition toward virtual

reality. If motor imagery already constitutes a multisensory embodied simulation, VR may strengthen this process through immersive environments capable of guiding, externalizing, and enriching perceptual-motor experience (Krüger et al., 2024). Consequently, the transition from body visualization to VR does not represent an epistemological rupture, but rather a technological extension of the enactive approach to motor learning.

4. Virtual Reality as an Enactive Methodological Device

Virtual reality is assuming an increasingly relevant role in motor rehabilitation and kinesiological reflection because it enables the design of learning environments in which experimental control, perceptual immersion, task adaptation, and performance monitoring can be dynamically integrated. Recent literature shows that VR offers specific advantages in terms of repetition, feedback, motivation, process documentation, and the possibility of manipulating task variables with a high degree of precision. However, the methodological value of VR does not depend solely on its technological dimension, but on the quality of the relationship it is able to establish between subject, action, and environment. In other words, VR becomes truly meaningful in kinesiology when it does not merely simulate scenarios, but allows a meaningful, adaptive, and task-oriented motor experience. From this perspective, the contribution of Haar, Sundar, and Faisal (2021) is particularly significant because it demonstrates how embodied virtual reality can be used to study motor learning in real tasks while maintaining strong correspondence between visual feedback, bodily interaction, and environmental control. The authors argue that embodied VR makes it possible to manipulate feedback and introduce perturbations in complex motor tasks while preserving, as much as possible, the sense of embodiment, namely the perception of being in one's

own body, controlling it, and acting effectively within the environment. This aspect is crucial: if VR loses the bodily grounding of experience, it risks becoming a spectacular but scarcely transferable mediation; conversely, when agency, self-location, and sensory integration are preserved, it may become an authentic enactive device for motor learning. Within this framework, Dynamics VR may be interpreted as a technology of particular applicative interest. According to information reported on the official website, the platform is designed for clinical rehabilitation sessions and allows professionals to select exercises according to therapeutic goals, regulate task difficulty, monitor execution, and collect follow-up data between sessions (Dynamics VR, 2026). The system is also presented as a supervised immersive environment characterized by rapid setup, team training, and the use of functional exercises adapted to clinical objectives. Although such information derives from an industry source and does not in itself constitute independent validation, it nevertheless reflects a structure of use coherent with principles currently considered central in VR-based rehabilitation: task specificity, adaptability, feedback, clinical supervision, and continuity of monitoring.

Table 1. Comparison Between Intervention Models

Dimension	Traditional Biomechanical Approach	Body Visualization	Immersive VR / Dynamics VR
Conception of the body	Body as a system to be mechanically analyzed and corrected	Body as internally simulated and lived experience	Body as an agent immersed in an interactive and monitorable environment
Methodological focus	Measurement, alignment, and movement efficiency	Multisensory mental simulation of movement	Immersive interaction with functional tasks and real-time feedback

Type of feedback	Predominantly external, observational, or instrumental	Internal, imaginative, and kinesthetic	Integrated: visual, attentional, motivational, and performance-based
Role of the subject	Executor of corrective tasks	Subject who anticipates and organizes action	Active subject who explores, adapts, and learns within the task
Context variability	Relatively low	Moderate, mediated by imagery guidance	High, digitally adjustable by the clinician
Traceability of progress	Possible, but not always continuous	Limited	Explicit data collection and follow-up declared by the platform

The table shows that VR does not replace either biomechanics or body visualization, but rather positions itself as an integrative level. Indeed, it may combine attention to task precision with the embodied dimension of experience, offering subjects an environment in which movement is not simply executed or imagined, but lived in an immersive and regulated form. From an enactive perspective, this means that motor knowledge is not transmitted as an abstract model, but emerges through the dynamic coupling between body, task, and technologically modulated environment. Another central element concerns feedback. Literature on VR in rehabilitation emphasizes that the effectiveness of these environments depends on their capacity to provide meaningful repetition, immediate feedback, and adequate subject motivation. In the case of Dynamics VR, the official website states that the platform records parameters such as repetitions, joint range of motion, execution speed, and active time, enabling clinical decisions based on objective data and adjustments of task difficulty according to patient progress. Here too, interpretative caution

is necessary; nevertheless, the methodological point remains strong: VR may become a space in which feedback does not arrive only after action, but accompanies action itself and contributes to its regulation.

Table 2. Methodological Functions of Dynamics VR from a Kinesiological Perspective

Function	Description	Kinesiological Relevance
Selection of exercises according to therapeutic goals	The clinician sets exercises according to the target of the session	Supports task specificity and intervention personalization
Difficulty regulation	Difficulty is adapted and controlled during practice	Supports progression, load dosage, and functional adaptation
Supervised immersive environment	The patient performs functional exercises within a controlled virtual environment	Enhances engagement, attention, and situated practice
Monitoring and follow-up	Data collection between sessions and progress monitoring	Strengthens longitudinal evaluation and clinical decision-making
Motivational engagement	The platform reports increased motivation and adherence	Useful for continuity, engagement, and work on fear of movement
Safe exposure to movement	VR may facilitate exposure to movements avoided because of pain or fear	Relevant for functional recovery and motor relearning

These functions make Dynamics VR interesting not only as a technical tool, but also as a methodological environment capable of integrating practice, task adaptation, sensory feedback, and continuous regulation of action within a coherent learning experience. VR, when properly designed, allows the creation of specific affordances, namely opportunities for action calibrated to the subject's needs, useful for supporting adaptive motor exploration. In this perspective, movement is no longer reduced to the mechanical execution of a

gesture, but becomes a process of integration between bodily experience, cognition, and affectivity. It nevertheless remains a critical issue: VR must not produce a virtualization disconnected from the body. The challenge is not to replace reality with the virtual, but to use immersive technologies to reorganize the subject's relationship with real movement. In this sense, Dynamics VR appears methodologically promising not merely as a clinical system, but as an environment capable of supporting functional recovery, motor reorganization, and the transfer of acquired skills toward concrete operational situations. From this perspective, virtual immersion may contribute to reducing the traditional separation between the technological device and bodily experience, promoting a relationship between simulation, perception, and movement coherent with the enactive approach to motor learning.

5. Pedagogical and Professional Implications in Kinesiological Training

The integration between body visualization and virtual reality raises important questions for the education of kinesiologists and health professionals. Indeed, learning processes can no longer be interpreted solely as the acquisition of predefined schemas, but rather as a process motivated by perception, attribution of meaning, and adaptive bodily experience. In this perspective, pedagogical approaches consistent with enactive models become central. It is no longer sufficient to transmit technical knowledge or prescribe standardized exercises; rather, it becomes necessary to design educational environments capable of constructing situated, modifiable, and highly personalized learning contexts. The use of technologies such as VR may therefore support a conception of movement education oriented toward active involvement, bodily awareness, and adaptive regulation of action through the integration of

multisensory information and situated interaction. From the perspective of embodied cognition (Ceciliani, 2018), kinesiology training cannot be reduced to the mere transmission of information. Rather, it must promote forms of knowledge rooted in the body and directly emerging from interaction between the ecological-dynamic subject and context, capable of understanding how perception, action, and organization self-determine within the relationship between movement and task. In this sense, pedagogical technologies should not be understood as external devices added to learning, but as environments contributing to the construction of bodily experience, feedback organization, and adaptive regulation of the task (Renshaw et al., 2010; Chow et al., 2011). Within this framework, it therefore becomes necessary to develop a techno-critical competence capable of integrating educational devices, immersive VR, and rehabilitative contexts coherently with the subject's needs and with the principles of embodied motor learning.

Table 3. Competencies of the Kinesiologist in the Enactive-Technological Approach

Competency Dimension	Educational Contents	Professional Purpose
Theoretical-epistemological	Phenomenology of the body, embodied cognition, enactivism, ecological approach, neuroscience of motor learning	Understanding movement as situated and embodied experience, and overcoming reductionist mechanistic views
Methodological-didactic	Design of learning environments, variability of practice, polysensory feedback, task specificity, constraints-led approach	Building adaptive educational pathways that promote exploration, adaptation, and bodily awareness
Technological-critical	Knowledge of VR, motor imagery, biofeedback, wearables, critical evaluation of technologies, integration in clinical and educational practice	Choosing and using technologies coherently with kinesiological and rehabilitative objectives

Evaluative-reflective	Qualitative and quantitative movement assessment, interpretation of VR data, process documentation, critical analysis of outcomes	Monitoring intervention effectiveness, adapting strategies, and supporting evidence-based decisions
Relational-communicative	Listening to the bodily experience of the subject, empathic communication, construction of trust in technological mediation	Promoting engagement, motivation, adherence to the intervention pathway
Ethical-professional	Accessibility of technologies, respect for corporeality, awareness of the limits of technological mediation, personalization	Ensuring ethically grounded interventions, avoiding technological dehumanization, and protecting subject dignity

This articulation demonstrates that the integration between body visualization and VR does not simply require the addition of technical content within educational pathways, but rather a comprehensive reorganization of the kinesiologist's professional profile. Training, in fact, cannot be limited to the transmission of separate disciplinary knowledge such as anatomy, physiology, biomechanics, or psychology; instead, it must foster integrated competencies capable of thinking and acting within the complexity of motor experience (D'Anna & Gomez Paloma, 2019). In particular, the kinesiologist must be able to critically interpret the relationship between technology and corporeality, avoiding both the prejudicial rejection of technological mediation and the illusion that technology can replace educational or clinical relationships. A second aspect concerns VR-mediated enactive pedagogy. If VR is designed coherently with the principles of embodied cognition, it may become an authentic space for motor learning rather than a mere simulation of movement. However, for this to occur, the kinesiologist must be capable of

designing experiences in which the subject acts, explores, receives feedback, and attributes meaning to their moving body. This requires the ability to construct adapted tasks, progressively modulate difficulty, sustain motivation, promote transfer from the virtual to the real context, and support reflection on bodily experience (Darekar, 2023). In other words, VR functions effectively only when the professional using it possesses solid pedagogical competencies and not merely technical expertise. A third element concerns critical and ethical issues. VR is not neutral: it may either enhance bodily experience or alienate it. It can promote inclusion and accessibility, or instead generate new forms of exclusion related to the digital divide, technological costs, or usability complexity (Laver et al., 2017). For this reason, kinesiology education must develop critical awareness regarding the limits and risks of technological mediation, encouraging a responsible, ethically oriented, and person-centered use of technology (Raiola et al., 2022;). Furthermore, VR should always be designed according to a logic of intervention personalization: each subject possesses a different motor history, specific needs, different levels of embodiment, and unique bodily experiences, and the kinesiologist must be capable of modulating the virtual environment according to this individuality. Finally, it should be emphasized that the enactive-technological approach does not deny the value of real practice, but rather prepares, guides, and strengthens it. Body visualization and VR do not replace actual movement; instead, they support it during phases of learning, relearning, consolidation, or overcoming perceptual and emotional barriers related to movement execution (Cappuccio, 2019). The kinesiologist of the future, therefore, will need to integrate embodied simulation, imagery practice, VR-based exercise, and real movement within coherent, progressive, and meaningful pathways for the subject, valuing each mediation as a resource for constructing awareness, autonomy, and motor competence.

6. Conclusions

The analysis developed in this contribution supports the argument that the convergence between body visualization and virtual reality represents a relevant theoretical and methodological turning point for contemporary kinesiology. The transition from the biomechanical paradigm to the paradigm of the lived body does not imply abandoning analytical knowledge about movement, but rather repositioning it within a broader framework in which perception, action, intentionality, and meaning attribution all contribute to the understanding of motor learning (D'Isanto et al., 2024). From this perspective, body visualization emerges as a methodology grounded in the embodied simulation of movement, capable of activating cognitive and sensorimotor processes relevant for the anticipation, regulation, and consolidation of action (Esposito et al., 2025; Raiola et al., 2020). Virtual reality, and particularly reference to systems such as Dynamics VR, becomes significant when it is understood not merely as a technical apparatus, but as a learning and intervention environment capable of amplifying the situated, immersive, and adaptive character of motor experience. The literature suggests that VR-based interventions may support functional improvements and processes of neural reorganization, especially when they are task-specific, progressive, and integrated into coherent rehabilitative or educational programs. In this direction, the relevance of Dynamics VR lies in the possibility of combining immersion, monitoring, difficulty regulation, and continuity of follow-up within a framework consistent with the enactive-technological approach to motor learning (D'Elia et al., 2020). For kinesiology, this implies the necessity of educating professionals capable not only of using innovative tools, but also of critically interpreting them and integrating them into pathways centered on corporeality, personalization, and the quality of the subject's experience. In this

sense, the future challenge concerns not merely the adoption of technology, but the construction of a methodological culture in which body visualization, VR, and real motor practice coherently contribute to education, functional recovery, and the development of motor competence.

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