ASSESSING SPORT PERFORMANCE IN THE AGE OF NEUROSCIENCE: THE BRAIN, THE BODY AND LEARNING IN COMPLEX ADAPTIVE SYSTEMS.

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ABSTRACT
This contribution examines the process of sport performance assessment in light of recent developments in motor neuroscience and complex adaptive systems theory, proposing an integrated perspective. Performance is conceptualized as an emergent phenomenon arising from the dynamic interaction between brain, body, and environment, in which biological, psychological, technical, and contextual factors are deeply interconnected. Within this framework, assessment is no longer limited to the quantitative recording of performance indicators, but becomes an interpretative process aimed at understanding the quality of relationships among system components. Particular attention is paid to the importance of combining tests and measurements with in-context observation in order to more comprehensively assess the athlete's perceptual and decision-making abilities. The increasing use of advanced technologies, such as tracking systems and wearable sensors, has significantly expanded data collection possibilities; however, it also requires critical interpretative skills to transform data into meaningful knowledge. The contribution also highlights the pedagogical implications of assessment, redefining it as a continuous and generative process that supports learning and fosters adaptive competence. Ultimately, an integrated systemic model of performance assessment is proposed, aligned with contemporary challenges in sport education and movement pedagogy within complex environments.

KEYWORDS
performance assessment; neuroscience; complex adaptive systems; motor learning.

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1. Introduction

In the contemporary field of kinesiology and sports science, performance assessment is undergoing a profound theoretical and methodological transformation, driven by the convergence of neuroscience, complexity science and ecological approaches to learning. Whereas in the past the assessment process was predominantly geared towards measuring isolated variables, today there is an increasingly clear need to interpret performance as a dynamic, situated and relational phenomenon, in which motor behaviour is seen as an emergent expression of the interaction between brain, body and environment. Cognitive and motor neuroscience have contributed significantly to redefining how human action is conceived, moving beyond the classical computational paradigm that viewed the brain as a central information processor. In this new perspective, the brain is no longer considered a mere command centre, but a dynamic system integrated with the body and the environment, in which perceptual, decision-making and motor processes develop in a continuous and interdependent manner (Varela et al., 1991; Clark, 1997). This perspective has found a theoretical synthesis in the embodied cognition approach, according to which cognition is deeply rooted in bodily experience and interactions with the environment (Wilson, 2002). At the same time, the ecological dynamics paradigm has provided a particularly effective interpretative framework for understanding motor learning and sport performance. According to this approach, behaviour emerges from the interaction between the constraints of the organism, the task and the environment, forming a complex adaptive system in constant evolution (Newell, 1986; Davids et al., 2008). From this perspective, performance cannot be reduced to a sequence of standardised technical executions, but must be interpreted as an adaptive process, characterised by functional variability and the ability to respond to situational

demands. Several studies have highlighted that motor learning should be interpreted as a dynamic and complex process, in which the athlete builds their skills through continuous interaction with the environment and with the situational demands of the task (Schmidt, 1975; Pacheco et al., 2019; Hristovski et al., 2011). From this perspective, the most effective teaching methods are those that are open and adaptive, capable of stimulating processes of perception, exploration and decision-making, whilst promoting the development of body awareness and motor autonomy. Recent research in the field of sports science has also confirmed that training programmes based on perceptual adaptation and the variability of motor situations produce positive effects on performance and cognitive processes in youth sport (Altavilla, 2021; Raiola et al., 2025). Within this theoretical framework, the issue of assessment takes on central importance. Assessment no longer means merely measuring quantitative parameters, but involves the ability to interpret dynamic patterns of behaviour, recognising the role of perception, decision-making and adaptation. As Safrit (1990) emphasised, the distinction between measurement and assessment highlights the difference between objective data and interpretative processes; however, in contemporary perspectives, this distinction tends to merge into a unified process, in which data only acquire meaning within a relational context. In this regard, D'Isanto et al. (2019) highlight how the assessment of sport performance must integrate theoretical aspects and practical guidelines, taking into account both measurement tools and the qualitative dimensions of motor action. This paper aims to analyse the process of assessing sport performance in the light of neuroscience and models of complex adaptive systems, with the aim of outlining an integrated theoretical perspective that can guide both research and teaching practice. In

particular, three fundamental aspects will be explored: the complex nature of performance, the role of measurement and technology in data collection, and the pedagogical implications for physical and sports education.

2. Sport performance as an expression of complex neuromotor systems

In the light of neuroscience and the science of complexity, sport performance can be interpreted as an emergent phenomenon arising from the dynamic interaction between biological, genetic, psychological, technical, tactical and environmental factors. It is therefore not simply the sum of isolated skills, but an adaptive, multi-level system in which each component contributes to performance in an interdependent manner. In this context, the relationship between hereditary and acquired factors takes on particular importance. Research on genetics applied to sport shows how aerobic capacity, body composition, muscle structure and certain personality traits can be influenced by genetic heritage (Bouchard et al., 1997). However, such predispositions do not rigidly determine performance, as they interact with training and individual experiences. This is why the concept of trainability is central: it refers to the body's ability to adapt to training stimuli and to modify its motor potential (Issurin et al., 2006). From a neuroscientific perspective, this adaptability depends on the plasticity of the nervous system, that is, on the brain's ability to reorganise its connections in response to experience. Motor learning does not, therefore, consist in the acquisition of fixed schemas, but in the progressive construction of coordinative patterns that emerge from the interaction between neural processes, bodily constraints and the environment (Kelso, 1995). Performance must therefore be regarded as a dynamic and constantly evolving process. An effective interpretative framework is provided

by Newell's constraint model (1986), according to which motor behaviour emerges from the interaction between the constraints of the organism, the task and the environment. The first include physical, physiological and psychological characteristics; the second concern the specific demands of the activity; the third include both physical elements and social factors. From this interaction arise behaviours that organise themselves spontaneously and require a constant balance between stability and variability. The athlete does indeed develop relatively stable coordination patterns, but must also know how to adapt them to different situations. Psychological factors also profoundly influence performance. Stress, concentration and emotional regulation have a significant impact on sport results (Raglin, 2001). Often, the difference between success and failure depends on the ability to maintain a balance between emotional arousal and cognitive control, confirming the integration of biological, cognitive and emotional dimensions (Lopez et al., 2020). Sport technique should also be understood as an adaptive system rather than simply the reproduction of standardised movements. It develops through a continuous process of adaptation in which error plays an essential role in learning and adjustment (Lees, 2002). From this perspective, the coach's role consists primarily of creating conditions that encourage the emergence of effective solutions. A further fundamental element is the athlete's health and well-being. Physical condition, nutrition, recovery and adaptability directly influence the expression of motor potential. Added to this are external factors such as social pressures, environmental expectations and improper practices such as doping, which artificially alter performance and demonstrate how it also depends on the social context. Overall, sport performance must be considered a complex neuromotor system in which biological, psychological, technical and environmental components are dynamically intertwined.

Consequently, performance assessment cannot be limited to the measurement of individual variables, but must adopt an integrated and interpretative perspective, capable of capturing the relationships between the various elements of the system.

3. Measurement, interpretation and technologies in the construction of motor and sports data

Within the field of motor and sports sciences, the measurement and evaluation of performance (Altavilla et al., 2024) play a central role both in terms of application and epistemology. Measurement consists of assigning numerical values to observable variables through objective and replicable procedures, whilst evaluation involves the interpretation and contextualisation of data to transform it into actionable information. In contemporary perspectives, however, these two dimensions tend to merge into a single process, in which data is considered the result of a complex construction involving instruments, theoretical models and interpretations. Traditionally, performance measurement is based on standardised tests designed to assess parameters such as strength, speed, endurance, flexibility and coordination. Such tests may be general, when they assess basic physical abilities, or specific, when they analyse skills related to a particular sport (Esposito et al., 2019). Their effectiveness depends on three fundamental criteria: validity, reliability and objectivity. However, these requirements are not sufficient to fully capture the complexity of real-world performance, which manifests itself in dynamic and unpredictable contexts. Tests are not merely assessment tools; they also play a regulatory role within the training process. Initial assessments enable the athlete's functional profile to be established, interim assessments monitor

adaptations, and final assessments compare results with the set objectives. In this way, assessment guides methodological choices and facilitates continuous adaptation of the training programme. Nevertheless, sporting performance cannot be understood solely through isolated tests. The competitive context is often the ideal setting for observing the athlete's behaviour, as it allows one to capture the interaction between perceptual, decision-making and adaptive components that rarely emerge under controlled conditions. The competition or real-game situation thus becomes a sort of 'ecological test', highlighting the limitations of a purely quantitative assessment. In recent years, advanced technologies have profoundly transformed the collection and analysis of sports data. Tools such as GPS, accelerometers, biometric sensors and video analysis systems allow for the real-time monitoring of numerous performance variables, offering an unprecedented amount of data. From a neuroscientific perspective, these technologies can be seen as an extension of the perceptual systems of the coach and technical staff. However, the overwhelming abundance of information can lead to 'data overload', making it necessary to develop interpretative models capable of selecting and contextualising the data. Performance analysis emphasises that data analysis must not be limited to description, but must aim to understand the underlying processes, identifying behavioural patterns and relationships between variables. From this perspective, measurement becomes a tool for accessing deeper levels of analysis. A further development is represented by artificial intelligence and machine learning, which enable the processing of large amounts of data, the identification of complex patterns and the prediction of performance trends. These technologies open up new possibilities for the personalisation of training and the management of training load, but they also require critical reflection on the ethical and methodological implications of their use. Overall, the

construction of sports data appears to be a multi-level process in which quantitative, qualitative and interpretative dimensions are closely intertwined. Data is therefore not a neutral and independent element, but the result of the relationship between observer, tools and context. Consequently, performance assessment must be rethought from an integrated perspective, one that combines scientific rigour with interpretation and an understanding of the complexity of human behaviour.

4. Assessment and teaching of movement: implications in educational and sporting contexts

The assessment of motor and sporting performance, understood as the expression of a complex and adaptive neuromotor system, cannot be reduced to a mere technical or quantitative evaluation. Rather, it represents a fundamental component of the educational and training process, helping us to understand how individuals learn, adapt and develop skills in relation to environmental constraints. From this perspective, the role of the teacher and coach changes profoundly: they must no longer limit themselves to transmitting technical models to be imitated, but must interpret and guide complex processes, fostering the development of adaptive and decision-making skills in athletes and students (Schmidt & Lee, 2011). Assessment thus becomes a tool for guiding and adjusting the learning pathway. Initial assessment takes on a dynamic diagnostic function, as it allows for the identification not only of physical abilities but also of adaptation strategies, cognitive and emotional characteristics, and individual responses to stimuli. This enables the creation of personalised pathways and realistic goals. Interim assessment, on the other hand, serves a continuous monitoring function. The

data collected during teaching or sporting activities serve to understand the individual's adaptation to the stimuli provided and to adjust strategies and workloads flexibly. This approach is consistent with the concept of trainability, according to which the body's potential can be developed through appropriate stimuli (Bompa & Haff, 2009). A key aspect concerns overcoming the divide between standardised tests and real-world performance. Although tests provide useful data, they cannot replace the observation of behaviour in real-world situations, where perceptual, decision-making and adaptive abilities come to the fore. In educational contexts, assessment concerns not only physical and technical aspects, but also cognitive, emotional and relational ones. Skills such as collaboration, emotional regulation and decision-making become an integral part of motor competence (Whitehead, 2010). In this vein, the ecological approach to motor learning emphasises that teaching does not consist of transmitting ideal models, but of constructing environments that encourage exploration and adaptation (Davids et al., 2008). From this perspective, the teacher assumes the role of designer of meaningful educational situations. Technology also provides important support in performance assessment, as it allows for the collection of detailed data and the personalisation of teaching. However, its use must be accompanied by critical reflection, avoiding the reduction of assessment to an exclusively quantitative dimension. Assessment also has a strong motivational dimension: if viewed merely as a judgement, it can cause anxiety; however, when placed within an appropriate educational context, it can foster awareness, engagement and personal growth. For this reason, it is important to place greater value on the learning process than on the final result alone (Deci & Ryan, 2000). Finally, assessment also contributes to injury prevention and health promotion, enabling the early identification of imbalances and functional deficiencies,

particularly in youth settings. It must therefore be understood as a dynamic, ongoing and contextualised process, capable of integrating scientific rigour and pedagogical sensitivity to promote the holistic development of the individual.

5. Conclusion

The assessment of sporting performance in the age of neuroscience is now seen as a complex and dynamic process that goes beyond reductionist models based on the simple measurement of isolated variables. Performance, in fact, arises from the continuous interaction between the brain, the body and the environment, taking the form of an adaptive system that cannot be interpreted through linear or deterministic approaches. From this perspective, there is a need to move from a static measurement approach to an assessment understood as an interpretative process, capable of analysing the quality of the relationships between the various factors of performance. Tests are useful tools for gathering information, but they are not sufficient to explain the complexity of performance, which finds its most authentic expression in real-life situations of play and action. Advanced technologies have expanded the possibilities for analysis, allowing for increasingly precise and continuous monitoring of performance parameters. However, the vast amount of data available does not automatically guarantee greater understanding: instead, it becomes essential to develop interpretative skills capable of transforming information into useful knowledge. In this context, teachers and coaches take on a central role, as they are called upon to interpret the complexity of motor behaviour and to consciously guide learning processes. From an educational perspective, assessment should not be viewed merely as a final step, but as a mechanism capable of fostering learning. It thus becomes a tool for promoting

awareness, adaptation and the development of skills, placing greater value on the process rather than simply the outcome. The focus is therefore on the quality of the strategies adopted, the ability to respond to contextual constraints and the flexibility of behaviour. In conclusion, assessing sporting performance in the age of neuroscience means adopting a view of complexity as a resource rather than a limitation.

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