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"EXPLORATION AND ANALYSIS OF THE INTERACTIONS BETWEEN PHYSICAL LITERACY DOMAINS IN SCHOOL CONTEXTS"

"EXPLORACIÓN Y ANÁLISIS DE LAS INTERACCIONES ENTRE LOS DOMINIOS DE LA ALFABETIZACIÓN MOTRIZ EN CONTEXTOS ESCOLARES"

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CERTIFICAN:

Que el presente trabajo, titulado "Exploración y análisis de las interacciones entre los dominios de la alfabetización motriz en contextos escolares", ha sido realizado bajo su dirección, por D. Sergio Montalt García, para optar al grado de Doctor por la Universidad de Valencia. Habiéndose concluido, y reuniendo a su juicio las condiciones de originalidad y rigor científico necesarias, autoriza su presentación a fin de que pueda ser defendido ante el tribunal correspondiente.

Y para que así conste expide y firma la presente certificación en Valencia a 23 de julio de 2025.

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ABBREVIATIONS

AA: academic achievement

BDNF: Brain-Derived Neurotrophic Factor

BMI: Body Mass Index

CAMSA: Canadian Agility and Movement Skill Assessment

CP: cognitive performance

CRF: cardiorespiratory fitness

CVD: cardiovascular disease

DT: dual-tasking

IGF-1: Insulin-like Growth Factor 1

MC: motor competence

MVPA: moderate to vigorous physical activity

OA: Osteoarthritis

PA: physical activity

PL: Physical Literacy

SOM: Self-Organizing Map

UNESCO: United Nations Educational, Scientific and Cultural Organization

VEGF: Vascular Endothelial Growth Factor

WHO: World Health Organization

ABSTRACT

Physical Literacy (PL) has become consolidated over the past decade as a key construct for understanding comprehensive child development, by integrating physical, cognitive, psychological, and social dimensions. From a holistic perspective, PL is not limited to the acquisition of motor skills, but encompasses motivational, emotional, social, and cognitive aspects that directly influence active participation in movement contexts and, by extension, in students' global development. Within this framework, the main objective of this doctoral thesis is to analyze the interaction between the different domains that constitute PL and their relationship with relevant educational variables, such as cognitive and academic performance, in real school settings.

The thesis is structured around three complementary empirical studies, designed to advance the theoretical and applied understanding of PL and its connection with learning. The first study addresses a major methodological gap identified in the literature: the lack of tools that enable the simultaneous assessment of motor competence (MC) and cognitive performance in ecological conditions. To address this limitation, an innovative instrument was designed and validated based on the dual-task paradigm, adapting the *Canadian Agility and Movement Skill Assessment* (CAMSA) to include cognitive demands. This new test, called the Cognitive CAMSA (CAMSA-C), makes it possible to observe students' joint performance when simultaneously facing motor and cognitive demands. The results show a significant decrease in motor performance under dual-task conditions (e.g., execution time and total score), compared to the single-task motor condition. Additionally, differentiated student profiles with varying performance patterns were identified, demonstrating that cognitive interference does not affect all students equally. While some maintain stable performance across conditions, others show improvements or declines depending on the nature of the task. These conclusions reinforce the value of CAMSA-C as a tool for integrated assessment of MC and cognitive performance, with strong potential for tailoring educational interventions to students' specific performance profiles.

The second study adopts a person-centered approach with the aim of identifying PL profiles among primary school students. Based on representative variables from the physical (e.g., MC, cardiorespiratory fitness [CRF]), psychological (e.g., perception of MC, perceived PL), and social (e.g., social identity, perceived social support) domains, six distinct profiles were identified using cluster analysis. These profiles were subsequently analyzed in relation to academic and cognitive performance. The results show that students with more balanced profiles—characterized by high levels across all three domains—also achieve better school performance (i.e., academic grades) and cognitive outcomes (i.e., math fluency and Stroop test performance). Conversely, students with lower levels in these domains presented the weakest cognitive outcomes, highlighting the combined influence of these factors on children's development. This approach provides a richer and more complex understanding of development and reinforces the explanatory value of PL as a multidimensional construct that goes beyond fragmented views of physical and cognitive domains.

The third study focuses on the psychological and motivational mechanisms that may mediate the relationship between MC, CRF and academic performance. A multiple mediation model was proposed and tested, incorporating variables such as self-determined motivation for physical activity, perceived MC, perceived physical fitness, academic self-perception, and perceived PL. The results confirm that both perceived PL and academic self-perception play a key mediating role in this relationship, explaining how physical capacities translate into better school outcomes through processes of self-perception and motivation. Additionally, the study examines the predictive role of physical activity. It was observed that its influence varies depending on the type of measurement used: self-reported physical activity predicts academic performance only when MC acts as the first mediator, while objectively measured moderate-to-vigorous physical activity predicts performance only when CRF occupies that position. These findings suggest differentiated pathways of influence, in which perceived physical activity reflects qualitative aspects related to self-perception and activity diversity, whereas objectively measured physical activity reflects effort intensity and duration, more closely related to physiological adaptations.

Overall, this thesis provides robust, rigorous, and up-to-date empirical evidence on the explanatory value of PL in school contexts. The findings from the three studies highlight the need to adopt an interdisciplinary perspective that integrates physical, cognitive, psychological, and social factors involved in child development and learning. Furthermore, they position PL as a valuable conceptual and practical framework for designing more inclusive and contextualized educational interventions aimed not only at improving MC, but also at promoting students' emotional well-being, motivation, and academic success throughout their schooling years.

RESUMEN

La Alfabetización Motriz (AM) se ha consolidado en la última década como un constructo clave para comprender el desarrollo integral en la infancia, al integrar dimensiones físicas, cognitivas, psicológicas y sociales. Desde un enfoque holístico, la AM no se limita a la adquisición de habilidades motrices, sino que engloba aspectos motivacionales, emocionales, sociales y cognitivos que inciden directamente en la participación activa en contextos de movimiento y, por extensión, en el desarrollo global del alumnado. En este marco, la presente tesis doctoral tiene como objetivo principal analizar la interacción entre los distintos dominios que conforman la AM y su relación con variables educativas relevantes, como el rendimiento cognitivo y académico, en contextos escolares reales.

La tesis se estructura en tres estudios empíricos complementarios, diseñados para avanzar en la comprensión teórica y aplicada de la AM y su vínculo con el aprendizaje. El primer estudio aborda una importante carencia metodológica detectada en la literatura especializada: la falta de instrumentos que permitan evaluar de forma simultánea la competencia motriz (CM) y el rendimiento cognitivo en condiciones ecológicas. Para responder a esta limitación, se diseña y valida un instrumento innovador basado en el paradigma de doble tarea, adaptando el *Canadian Agility and Movement Skill Assessment* (CAMSA) para incluir demandas cognitivas. El nuevo test, denominado CAMSA-Cognitivo (CAMSA-C), permite observar el rendimiento conjunto del alumnado cuando se enfrentan simultáneamente a exigencias motrices y cognitivas. Los resultados evidencian una disminución significativa del rendimiento motriz en condiciones de doble tarea (e.g., tiempo de ejecución y puntuación total), en comparación con la tarea motriz simple. Asimismo, se identifican perfiles diferenciados de alumnado con patrones diversos de desempeño, lo que demuestra

que la interferencia cognitiva no afecta por igual a todos los estudiantes. Algunos mantienen un rendimiento estable entre condiciones, mientras que otros presentan mejoras o deterioros según el tipo de demanda. Estas conclusiones refuerzan la utilidad del CAMSA-C para evaluar de manera integrada la CM y el rendimiento cognitivo, y su potencial como herramienta para adaptar las intervenciones educativas al perfil de desempeño de cada alumno.

El segundo estudio adopta una perspectiva centrada en la persona, con el objetivo de identificar perfiles de AM en alumnado de educación primaria. A partir de variables representativas de los dominios físico (e.g., CM, aptitud cardiorrespiratoria [ACR]), psicológico (e.g., percepción de CM, percepción de AM) y social (e.g., identidad social, apoyo social percibido), se establecen configuraciones distintas mediante análisis de conglomerados. Se identifican seis perfiles de alumnado según la interacción entre dichas variables, los cuales se analizan posteriormente en relación con el rendimiento académico y cognitivo. Los resultados muestran que aquellos estudiantes con perfiles más equilibrados —caracterizados por altos niveles en los tres dominios— presentan también un mejor desempeño escolar (i.e., calificaciones académicas) y cognitivo (i.e., fluidez matemática y prueba de Stroop). En cambio, los perfiles con niveles bajos en estos dominios muestran los resultados más reducidos en el ámbito cognitivo, lo que subraya la influencia conjunta de estos factores en el desarrollo infantil. Este enfoque aporta una comprensión más rica y compleja del desarrollo, y refuerza el valor explicativo de la AM como constructo multidimensional que trasciende visiones fragmentadas de lo físico y lo cognitivo.

El tercer estudio se centra en los mecanismos psicológicos y motivacionales que podrían mediar la relación entre la CM, la ACR y el rendimiento académico. Se plantea y contrasta un modelo de mediación múltiple que incluye variables como la motivación autodeterminada hacia la actividad física, la percepción de CM, la percepción de condición física, la autopercepción académica y la AM percibida. Los resultados confirman que tanto la AM como el rendimiento académico percibido desempeñan un papel mediador clave en esta relación, explicando cómo las capacidades físicas se traducen en un mejor rendimiento escolar a través de procesos de autopercepción y motivación. Asimismo, se examina el papel adicional de la actividad física como predictor. Se observa que su influencia varía en función del tipo de medida utilizada: la actividad física autorreportada predice el rendimiento académico únicamente cuando la CM actúa como primer mediador, mientras que la actividad física moderada-vigorosa medida por acelerometría lo hace solo cuando la ACR ocupa dicha posición. Estos hallazgos sugieren trayectorias diferenciadas de influencia, donde la actividad física percibida refleja aspectos cualitativos relacionados con la autopercepción y la diversidad de experiencias, y la actividad física medida objetivamente refleja la intensidad y duración del esfuerzo, más estrechamente relacionadas con adaptaciones fisiológicas.

En conjunto, esta tesis aporta evidencia empírica sólida, rigurosa y actualizada sobre el valor explicativo de la AM en el contexto escolar. Los hallazgos de los tres estudios refuerzan la necesidad de adoptar una perspectiva interdisciplinar que integre de forma articulada los factores físicos, cognitivos, psicológicos y sociales que intervienen en el desarrollo infantil y el aprendizaje. Asimismo, posicionan la AM como un marco conceptual y práctico valioso para diseñar intervenciones educativas más inclusivas y contextualizadas, orientadas no solo a la mejora de la competencia motriz, sino también al fomento del bienestar emocional, la motivación y el éxito académico del alumnado en las etapas escolares.

RESUM

L'Alfabetització Motriu (AM) s'ha consolidat en l'última dècada com un constructe clau per a comprendre el desenvolupament integral en la infància, en integrar dimensions físiques, cognitives, psicològiques i socials. Des d'un enfocament holístic, l'AM no es limita a l'adquisició d'habilitats motrius, sinó que engloba aspectes motivacionals, emocionals, socials i cognitius que incidixen directament en la participació activa en contextos de moviment i, per extensió, en el desenvolupament global de l'alumnat. En aquest marc, la present tesi doctoral té com a objectiu principal analitzar la interacció entre els diferents dominis que conformen l'AM i la seua relació amb variables educatives rellevants, com el rendiment cognitiu i acadèmic, en contextos escolars reals.

La tesi s'estructura en tres estudis empírics complementaris, dissenyats per a avançar en la comprensió teòrica i aplicada de l'AM i el seu vincle amb l'aprenentatge. El primer estudi aborda una important carència metodològica detectada en la literatura especialitzada: la falta d'instruments que permeten avaluar de manera simultània la competència motriu (CM) i el rendiment cognitiu en condicions ecològiques. Per a respondre a esta limitació, es dissenya i valguda un instrument innovador basat en el paradigma de doble tasca, adaptant el *Canadian Agility and Movement Skill Assessment* (CAMSA) per a incloure demandes cognitives. El nou test, denominat CAMSA-Cognitiu (CAMSA-C), permet observar el rendiment conjunt de l'alumnat quan s'enfronten simultàniament a exigències motrius i cognitives. Els resultats evidencien una disminució significativa del rendiment motriu en condicions de doble tasca (e.g., temps d'execució i puntuació total), en comparació amb la tasca motriu simple. Així mateix, s'identifiquen perfils diferenciats d'alumnat amb patrons diversos d'acompliment, la qual cosa demostra que la interferència cognitiva no afecta per

igual a tots els estudiants. Alguns mantenen un rendiment estable entre condicions, mentres que uns altres presenten millores o deterioracions segons el tipus de demanda. Aquestes conclusions reforcen la utilitat del CAMSA-C per a avaluar de manera integrada la CM i el rendiment cognitiu, i el seu potencial com a ferramenta per a adaptar les intervencions educatives al perfil d'acompliment de cada alumne.

El segon estudi adopta una perspectiva centrada en la persona, amb l'objectiu d'identificar perfils d'AM en alumnat d'educació primària. A partir de variables representatives dels dominis físic (e.g., CM, aptitud cardiorespiratòria [ACR]), psicològic (e.g., percepció de CM, percepció d'AM) i social (e.g., identitat social, suport social percebut), s'establixen configuracions distintes mitjançant anàlisis de conglomerats. S'identifiquen sis perfils d'alumnat segons la interacció entre aquestes variables, els quals s'analitzen posteriorment en relació amb el rendiment acadèmic i cognitiu. Els resultats mostren que aquells estudiants amb perfils més equilibrats —caracteritzats per alts nivells en els tres dominis— presenten també un millor acompliment escolar (i.e., qualificacions acadèmiques) i cognitiu (i.e., fluïdesa matemàtica i prova de Stroop). En canvi, els perfils amb nivells baixos en estos dominis mostren els resultats més reduïts en l'àmbit cognitiu, la qual cosa subratlla la influència conjunta d'estos factors en el desenvolupament infantil. Aquest enfocament aporta una comprensió més rica i complexa del desenvolupament , i reforça el valor explicatiu de l'AM com a constructe multidimensional que transcendix visions fragmentades del físic i el cognitiu.

El tercer estudi se centra en els mecanismes psicològics i motivacionals que podrien mediar la relació entre la CM, l'ACR i el rendiment acadèmic. Es planteja i contrasta un model de mediació múltiple que inclou variables com la motivació autodeterminada cap a l'activitat física, la percepció de CM, la percepció de condició física, l'autopercepció acadèmica i l'AM percebuda. Els resultats confirmen que tant l'AM com el rendiment acadèmic percebut exercixen un paper mediador clau en esta relació, explicant com les capacitats físiques es traduïxen en un millor rendiment escolar a través de processos d'autopercepció i motivació. Així mateix, s'examina el paper addicional de l'activitat física com a predictor. S'observa que la seua influència varia en funció del tipus de mesura utilitzada: l'activitat física autoreportada prediu el rendiment acadèmic únicament quan la CM actua com a primer mediador, mentres que l'activitat física moderada-vigorosa mesura per accelerometria ho fa només quan l'ACR ocupa esta posició. Aquestes troballes suggerixen trajectòries diferenciades d'influència, on l'activitat física percebuda reflectix aspectes qualitatius relacionats amb l'autopercepció i la diversitat d'experiències, i l'activitat física mesurada objectivament reflectix la intensitat i duració de l'esforç, més estretament relacionades amb adaptacions fisiològiques.

En conjunt, esta tesi aporta evidència empírica sòlida, rigorosa i actualitzada sobre el valor explicatiu de l'AM en el context escolar. Les troballes dels tres estudis reforcen la necessitat d'adoptar una perspectiva interdisciplinària que integre de forma articulada els factors físics, cognitius, psicològics i socials que intervenen en el desenvolupament infantil i l'aprenentatge. Així mateix, posicionen l'AM com un marc conceptual i pràctic valuós per a dissenyar intervencions educatives més inclusives i contextualitzades, orientades no sols a la millora de la competència motriu, sinó també al foment del benestar emocional, la motivació i l'èxit acadèmic de l'alumnat en les etapes escolars.

GENERAL INTRODUCTION

GENERAL INTRODUCTION

1.1. PHYSICAL LITERACY

1.1.1. The Physical Literacy concept

In recent years, the concept of Physical Literacy (PL) has become increasingly prominent in the fields of Physical Education, the promotion of physical activity (PA), and public health (Jurbala, 2015). This growing attention is partly due to the need to reconsider the role of Physical Education in a society characterized by sedentary lifestyles and rising inequalities in access to and engagement with quality movement experiences (Belanger et al., 2018).

The PL construct initially emerged as an alternative to the notion of being "physically educated," a dominant concept until the 1990s that focused on the acquisition of specific physical skills and technical knowledge related to PA (Whitehead, 2001). However, this perspective began to be seen as insufficient to meet the evolving demands of Physical Education, as it overlooked other dimensions necessary for a more holistic and meaningful understanding of human movement (Whitehead, 2001). In this regard, Margaret Whitehead was one of the first scholars to conceptualize PL from a philosophical standpoint, emphasizing that PL is essential for fully experiencing human life. Rather than providing a fixed or detailed definition, Whitehead highlighted the importance of activating integrated bodily capacities as a means to unlock individual potential and enhance quality of life.

Since its initial formulation, the definition of PL has been expanded and reinterpreted from various perspectives, reflecting the conceptual richness and complexity of the construct. In her early work, Whitehead described it as a competence that encompasses the entirety of bodily experience, integrating both motor proficiency across diverse contexts and a positive attitude toward movement as a pathway to personal fulfillment (Whitehead, 2001). In 2009, Mandigo et al. (2009) defined PL as the ability of individuals to move with competence in a wide range of physical activities, thereby contributing to their overall development. From an institutional perspective, UNESCO has characterized PL as the combination of ability, confidence, and motivation needed to engage in lifelong participation in PA (2004). More recently, a consensus statement has articulated the core elements of the construct, defining it as the motivation, confidence, physical competence, knowledge, and understanding to value and take responsibility for engaging in physical activities throughout life (Cairney et al., 2016).

In light of this diversity of definitions, and in an effort to contextualize the term within Spanish-speaking contexts, its translation has received particular attention. While the literal translation of PL into Spanish would be *Alfabetización Física*, such a term falls short in conveying the holistic and integrative nature of the construct. To address this semantic dissonance, a more culturally and linguistically adapted conceptualization has been proposed — one that underscores the multidimensional essence of PL. As such, the term *Alfabetización Motriz* has been put forward as the most appropriate option to preserve the original spirit of the concept and to facilitate its incorporation into educational and social contexts in Spanish-speaking countries (Santos-Miranda et al., Unpublished manuscript).

Despite their nuances, all these definitions share a common core: PL is not limited to improving proficiency in performing motor skills, but also involves feeling competent and confident in navigating diverse contexts, from domestic settings to natural or sport environments, while experiencing enjoyment, autonomy, and a sense of identity through movement (Cairney et al., 2016).

Unlike other constructs focused solely on physical or technical ability, PL acknowledges the interaction between body and mind as an inseparable unity (Whitehead, 2013). In this sense, it is understood as a global competence grounded in the human potential to interact with the world in a fluid, meaningful, and effective way through movement (Cairney et al., 2019; Whitehead, 2019). This perspective is rooted in philosophical traditions such as existentialism, monism, and phenomenology, which emphasize the lived bodily experience as an essential means of knowledge, expression, and connection with the environment (Edwards et al., 2017; Whitehead, 2013).

Currently, PL is structured around four interrelated domains: the physical, psychological, social, and cognitive domains (Longmuir et al., 2015), a topic that will be further developed in Section 1.2. Achieving adequate levels of PL not only supports motor and cognitive development, but also contributes to self-fulfillment, self-confidence, and the consolidation of positive self-esteem (Agans et al., 2024; Cairney et al., 2019; Edwards et al., 2017). Thanks to its multidimensional structure, PL offers a holistic approach that allows human movement to be understood not only as a physical skill, but also as a phenomenon with emotional, social, and cognitive implications (Cairney et al., 2019).

In educational contexts, PL has become a key framework for transforming the teaching of Physical Education, promoting an inclusive, equitable, and student-centered approach focused on holistic development (Mandigo et al., 2009). Various organizations and institutions have recognized its educational value and advocate for its integration into educational, sports, and health policies (Mandigo et al., 2009; Whitehead, 2013). Likewise, the scientific literature has highlighted its potential to promote sustained and active participation in PA, enhance emotional well-being, improve social competence, and foster healthy lifestyle habits (Cairney et al., 2019; Edwards et al., 2017).

Taken together, PL also emerges as a protective factor for health throughout the life course (Cairney et al., 2019). Although further scientific evidence is needed, several studies suggest that higher levels of PL, by enhancing motor competence (MC), motivation, and self-efficacy in children, may support regular engagement in PA and help prevent issues related to sedentary lifestyles (Cairney et al., 2019; Dudley et al., 2017).

Given the growing relevance and potential of PL, it is essential to continue deepening our understanding of its development and assessment processes (Young et al., 2020). Despite conceptual and practical advances, several key challenges still remain. On the one hand, the multiplicity of definitions and interpretative frameworks has made it difficult to reach academic consensus and has hindered comparability across studies (Edwards et al., 2017). On the other hand, assessing PL in real-world contexts poses significant methodological challenges, particularly when attempting to capture the interaction among its various domains (Edwards et al., 2018). In this context, further research is needed to explore its measurement, pedagogical applicability, and domain interactions in order to establish a robust theoretical-practical framework to inform future interventions in both educational and public health settings (Cairney et al., 2019). This conceptual breadth is structured around four interrelated domains, as outlined below.

1.1.2. Physical Literacy domains

In line with the concept of PL, which encompasses multiple elements within a holistic and integrative framework, it cannot be reduced solely to its physical or technical component, but must be understood as a complex experience influenced by various dimensions of human development (Keegan et al., 2019). Based on the Australian PL framework (Keegan et al., 2017), this construct is structured around four fundamental and interrelated domains: physical, psychological, social, and cognitive (Figure 1).

Figure 1. Components of the Australian Physical Literacy framework. Adapted from Sport Australia (Sport Australia, 2019).

These domains allow motor behavior to be understood as the outcome of a multidimensional process (Cairney et al., 2019). Each domain represents a specific lens through which PL is expressed and developed, yet none of them operates in isolation. On the contrary, the richness of the construct lies precisely in the ongoing interaction among these areas, giving rise to unique and diverse developmental trajectories.

This integrated perspective is especially relevant in educational contexts and in the promotion of PA, where recognizing the individual diversity of students is essential (Mandigo et al., 2009). Each person develops differently, with unique strengths, interests, motivations, and social contexts. Therefore, PL must be understood as a personal and dynamic process, shaped by both internal factors (e.g., perceived competence or motivation) and external factors (e.g., social environment, accessibility, or quality of instruction).

By addressing the domains in a differentiated yet interconnected manner, a more inclusive and comprehensive view of motor development is promoted. This approach calls for the design of pedagogical interventions that are more responsive to the individual and contextual needs of each student, encourage more meaningful participation in PA, and contribute effectively to the development of active, healthy, and sustainable lifestyles over time (Dudley et al., 2017).

The following section provides a detailed description of the four domains that form the structural foundation of PL, focusing on their definition, relevance, and interconnections with the other dimensions.

1.1.2.1. Physical domain

The physical domain focuses on the bodily capacities required to move effectively, safely, and adaptively across various contexts and throughout the life course. This domain includes both proficiency in performing motor skills (e.g., running, jumping, throwing, or balancing) and the body control and physical fitness acquired and applied through movement (Cairney et al., 2016). Through its development, individuals can build positive relationships with movement, as well as feel confident and motivated to participate in physical activities (Sport Australia, 2019). PL thus acknowledges that human movement occurs across multiple environments (e.g., land, water, ice, or snow) (Hastie & Wallhead, 2015), and requires individuals to adapt effectively through postural control, coordination, and mastery of body and space (Keegan et al., 2017).

Developing the physical domain involves acquiring and improving a wide range of physical and motor abilities (Belanger et al., 2018; Comeau et al., 2017). These include fundamental movement skills, object manipulation and control, coordination, speed, agility, flexibility, balance, reaction time, muscular strength, and both muscular and cardiorespiratory endurance (Keegan et al., 2017). These capacities not only facilitate participation in a wide variety of physical activities, but also serve as a foundation for building an active and healthy life trajectory (Henrique et al., 2016; Jaakkola et al., 2016; Lloyd et al., 2014).

In line with the holistic approach of PL, the physical domain cannot be interpreted as an isolated construct but as one that constantly interacts with the psychological, social, and cognitive domains. How an individual moves is influenced by their perceived competence, emotions, level of motivation, social relationships, and understanding of their environment. Therefore, it is not enough to develop strength or technical proficiency; it is equally important to foster confidence, knowledge, and body awareness in order to consolidate a complete and meaningful form of PL (Cornish et al., 2020).

Numerous studies have shown that higher levels of MC are associated with more frequent PA participation (Cattuzzo et al., 2016; Lubans et al., 2010; Stodden et al., 2008), better physical and mental health (Bao et al., 2024; Robinson et al., 2015), lower rates of overweight (Bonvin et al., 2012; Comeau et al., 2017), and reduced risk of sedentary behavior (Adank et al., 2018; Santos et al., 2021). This relationship has fueled growing interest in PL research in recent years (Barnett et al., 2023). Such interest reflects the increasing scientific consensus regarding the central role of PL in promoting active and healthy lifestyles, as well as in preventing inactivity-related diseases.

Thus, the physical domain is not only related to athletic performance or technical skill, but constitutes an essential tool for overall well-being. Its development contributes to improved motor efficiency, reduced risk of injury, increased self-confidence in movement contexts — in short, enhanced MC (Bandeira et al., 2025) — and supports sustained participation in recreational, educational, and social physical activities (Jayanthi & Brenner, 2017; Roetert et al., 2018).

1.1.2.2. Psychological domain

The psychological domain encompasses a set of internal factors that shape an individual's disposition toward movement, their emotional relationship with PA, and how they perceive themselves in motor contexts (Cairney et al., 2019). This domain includes constructs such as intrinsic motivation, self-confidence, perceived competence, resilience, emotional regulation, and enjoyment of movement (Edwards et al., 2017), all of which are essential for participation in PA to be meaningful, sustained, and satisfying (Cairney et al., 2019; Ng et al., 2012).

An individual with well-developed psychological capacities is understood to approach motor challenges with a positive attitude, persist through difficulties, value their achievements, and acknowledge their limitations without excessive frustration (Sport Australia, 2019). This type of psychological profile fosters autonomy, self-efficacy, and the development of a positive relationship with the moving body (Weerackody et al., 2023).

There is evidence that several psychological factors are not only associated with higher levels of PA (Cortis et al., 2017), but also predict long-term adherence (Amireault et al., 2013). Autonomous motivation, understood as motivation driven by interest and personal satisfaction, has been shown to be one of the most influential variables in promoting PA engagement among children and adolescents (Chen et al., 2014; Deci & Ryan, 2000). Additionally, perceived MC plays a key mediating role between actual competence and active behavior (Ortega-Benaventet al., 2024), acting as a catalyst for sustained PA involvement (De Meester et al., 2020; Estevan et al., 2021; Stodden et al., 2008).

The development of the psychological domain is closely tied to emotional growth. Participation in enriching motor contexts can contribute to improved self-esteem, reduced anxiety levels, and the promotion of a healthy body image (Agans et al., 2024). For example, during the COVID-19 pandemic, children with higher levels of PL (including its psychological component) were more likely to meet PA guidelines even under adverse conditions, suggesting a protective role of this domain in limiting contexts (Mazzoli et al., 2024).

It is important to highlight that the psychological domain does not develop in isolation, but rather interacts continuously with the other domains of PL. For instance, a child with low perceived MC may show reduced motivation or insecurity when engaging in active play, which can negatively affect their motor experience and reduce participation in PA (Cairney et al., 2019; Ortega-Benavent et al., 2024). Similarly, social comparison or the quality of instruction received may either strengthen or undermine a child's confidence in motor practice (Dudley et al., 2017).

From an educational perspective, supporting psychological development goes beyond technical instruction. It requires the creation of motivating, safe, and appropriately competitive environments, where individual effort is recognized, self-assessment is encouraged, and the enjoyment of movement is promoted as a core value (Agans et al., 2013; Beni et al., 2017). These conditions seem to foster not only more active participation, but also greater sustainability over time (Teixeira et al., 2022).

The development of this domain reinforces autonomy and commitment to PA, shaping how individuals interpret and respond to motor challenges. This dimension serves as a bridge between elements of the physical domain and those related to self-perception, contributing to a comprehensive form of PL.

1.1.2.3. Social domain

The social domain refers to an individual's ability to engage with others and actively participate in movement contexts in a cooperative, respectful, and ethical manner. It also encompasses skills such as the ability to build and maintain respectful relationships, communicate and cooperate effectively with others, resolve conflicts, demonstrate leadership, and adopt ethical and moral principles that promote fair, inclusive, and equitable behavior. In addition, it includes the appreciation of cultural diversity within groups, organizations, and communities across various physical activities (Keegan et al., 2017).

While social development in educational settings has traditionally been addressed from a more general perspective, the construct of PL highlights its central role within movement experiences. Participation in PA typically occurs in social contexts, whether formal (e.g., Physical Education classes, team sports) or informal (e.g., free play, recreational activities) (Arufe-Giráldez et al., 2024). In these settings, social competencies not only support interaction, but also enrich the quality of the motor experience and may help promote sustained engagement in PA (Hu et al., 2021).

Unlike the psychological domain, which focuses on the individual's internal relationship with movement, the social domain centers on how individuals interact with others during movement experiences. However, both domains are closely interconnected: for example, a safe and positive social environment can enhance motivation, self-confidence, and perceived competence, while experiences of exclusion, teasing, or social pressure may inhibit motor behavior (Cairney et al., 2019; Menescardi & Estevan, 2021).

Recent research suggests that through observation and social interaction, children learn to replicate the behaviors of family members and peers regarding PA participation (Shen et al., 2018). These aspects not only influence the continuity of practice, but also have key educational value for fostering active citizenship, particularly during childhood and adolescence. For this reason, the development of this domain in PL extends beyond the realm of Physical Education and contributes to broader social competencies such as empathy, compassion, and inclusion, among others (Sport Australia, 2019).

In addition, the social domain takes on particular relevance from an inclusive perspective. Recognizing diversity in abilities, interests, cultures, and genders requires the design of movement experiences that promote equity and meaningful participation for all students. Such an approach positions movement not only as a means of individual development, but also as a vehicle for connection, dialogue, and collective construction (Robinson et al., 2018).

From a pedagogical standpoint, fostering the social domain involves creating learning environments that prioritize collaboration over competition, promote teamwork, peaceful conflict resolution, and the recognition of peers as learning partners. These conditions not only enrich the motor experience but also help strengthen the social fabric within school and community settings. In this regard, both family (Shen et al., 2018) and peer contexts (Monteiro et al., 2021) have been shown to be crucial for motor development and continued engagement in PA.

Therefore, this domain not only shapes opportunities for practice but also interacts with emotional and motivational development, contributing to meaningful movement experiences. Its transversal influence on the other domains makes it a key component in the comprehensive assessment of PL.

1.1.2.4. Cognitive domain

The cognitive domain refers to the mental processes involved in understanding, planning, decision-making, and evaluating within movement contexts. It includes the ability to interpret the physical environment, anticipate actions, reason about the moving body, and apply knowledge related to PA and health (Keegan et al., 2017). Furthermore, its development provides the mental scaffolding that allows movement to be integrated within a broader framework of meaning, imbuing it with intentionality, reflection, and learning (Cairney et al., 2019).

This domain is reflected in skills such as motor problem-solving, tactical decision-making, knowledge about the benefits of PA, understanding of rules and strategies, and the ability to self-regulate both cognitively and metacognitively during physical practice (Shearer et al., 2021). In this way, the cognitive domain not only supports technical execution but also enhances the quality of participation through critical thinking and informed decision-making.

The development of this domain is closely linked to the development of executive functions (i.e., working memory, inhibitory control, cognitive flexibility), particularly during childhood, as these functions are still maturing (Diamond, 2013). Participation in physical activities that involve understanding, reasoning, and decision-making requires the activation of these executive processes (Cao et al., 2024; García et al., 2023). These functions are essential for interpreting and applying rules, adjusting behavior in real time, and anticipating the consequences of one's actions, as often occurs in active play or sport settings (Brimmell et al., 2022). Therefore, incorporating the study of executive functions into PL research allows for a deeper understanding of the mechanisms that underpin the cognitive domain and its relationship with students' overall development.

Moreover, physical activities that include cognitive components — such as rule-based games, dual-task situations, or strategic sports — not only support motor development, but can also enhance academic performance and other indicators of cognitive functioning in the classroom (Pesce et al., 2013). In this sense, the cognitive domain offers a solid conceptual foundation for rethinking the role of movement in education, not merely as an end in itself, but as a means for fostering students' holistic development. Promoting this domain involves designing movement experiences rich in cognitive content, that invite reflection, exploration, anticipation, and the transfer of learning to other everyday contexts.

PL requires real-time decision-making, anticipation, and reasoning processes, particularly in sport or active play contexts(Shearer et al., 2021). These cognitive processes interact with motor skills, and their joint analysis is key to understanding how actions are executed effectively in complex situations.

1.1.2.5. The integration of the four domains

The analysis of the four domains that comprise PL (i.e., physical, psychological, social, and cognitive) allows for a deeper understanding of the complexity of human movement beyond its technical or functional dimension. Each domain represents a unique facet of development, but their true strength lies in the dynamic and ongoing interaction between them (Grauduszus et al., 2023).

For example, a child may have good MC (physical domain), but if they do not feel confident, motivated, or competent (psychological domain), they are unlikely to participate actively in physical activities. Similarly, if they do not feel accepted or integrated within the group (social domain), their motor learning experience may be limited. Furthermore, without an adequate understanding of the purpose of PA or the rules of a game (cognitive domain), participation loses depth and long-term value.

This holistic approach provides tools for designing pedagogical interventions that are more inclusive, personalized, and meaningful (Mandigo et al., 2009). In educational contexts, integrating these domains helps to address student diversity, promote equitable participation, and support the adoption of active and healthy lifestyles throughout the life course (Durden-Myers & Bartle, 2023).

Thus, PL understood through its four domains constitutes a comprehensive model for approaching movement development as a biopsychosocial phenomenon, contributing to individuals' physical, psychological, social, and cognitive well-being across all stages of life.

1.1.3. The impact of Physical Literacy on child development

PL has become a key construct for understanding and promoting holistic development during childhood. It involves a complex interaction between different domains, whose coordinated development supports active, healthy, and sustainable life trajectories (Cairney et al., 2019; Cornish et al., 2020).

A growing body of evidence has shown that PL levels in the early years are positively associated with greater participation in PA, as well as with psychosocial factors such as motivation, confidence, and perceived competence (Agans et al., 2024; Edwards et al., 2017). This process follows a positive feedback loop: when children develop their MC and engage in meaningful movement experiences, they tend to participate more frequently and with greater commitment in physical activities, which in turn reinforces their perceived competence and intrinsic motivation (Cairney et al., 2019) (Figure 2).

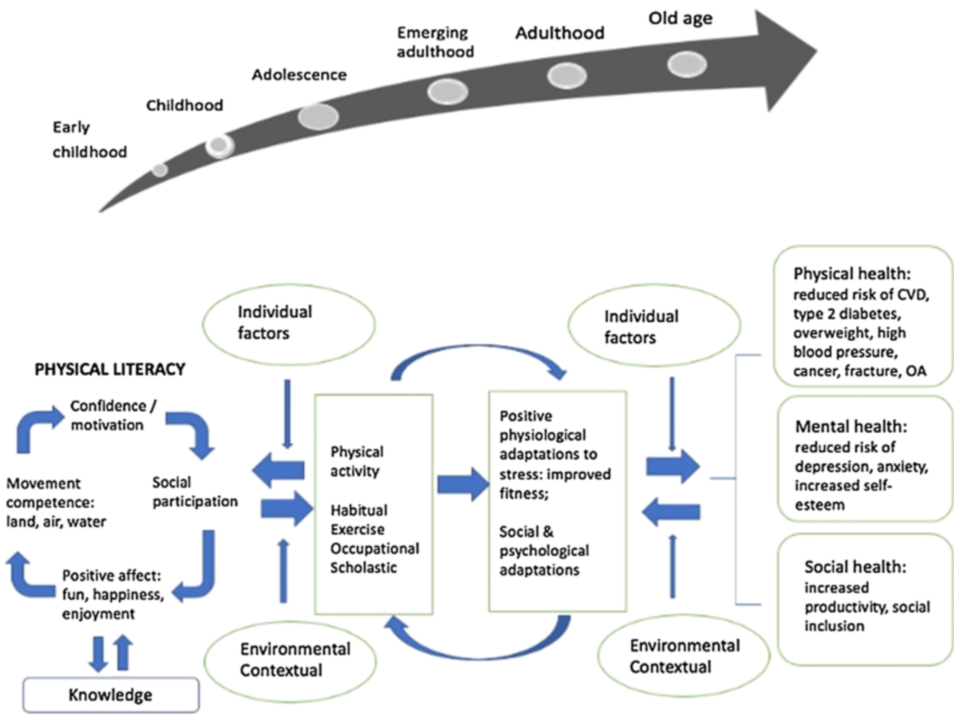

Figure 2. Conceptual model linking Physical Literacy, Physical Activity, and health. Proposed by Cairney et al. (2019). *Note*: CVD = cardiovascular disease, OA = osteoarthritis.

The benefits of sustained engagement in PA can manifest at the psychological level (e.g., through increased self-esteem, self-confidence, or social integration) (Babic et al., 2014; Dale et al., 2019), through physiological improvements [e.g., enhanced cardiorespiratory fitness (CRF), better body composition, and reduced risk of overweight or obesity] (Janssen & LeBlanc, 2010; Landry & Driscoll, 2012), or even cognitively (e.g., via improvements in executive functions or academic performance) (Donnelly et al., 2016; Poitras et al., 2016). This integrative perspective positions PL as a bridge between movement, health, and well-being, with the potential to positively shape life trajectories from an early age (Cairney et al., 2019).

Accordingly, interventions specifically designed to enhance PL have been shown to produce multiple benefits (Carlet al., 2022). In this regard, in their systematic review, Carl et al. (2022) demonstrated its impact across several domains. Furthermore, the authors observed improvements in MC and lower-body physical fitness. They also reported moderate positive effects on PA-related knowledge and understanding, on motivation and confidence, and on actual PA behavior. These findings reinforce the idea that PL not only promotes movement, but also fosters learning processes, personal development, and emotional well-being through meaningful movement experiences.

Romero-Martínez et al. (Romero-Martínez et al., 2024) also found positive effects in their systematic review of school-based interventions aimed at developing PL in children aged 8 to 12 years, either through integrated classroom PA or Physical Education. On the one hand, interventions based on classroom PA (e.g., active breaks) were shown to primarily improve children's attention while also promoting PA engagement. On the other hand, interventions delivered through Physical Education showed that after just one month, improvements were observed across all domains of PL. Students increased their level of MC (physical domain), their self-perception and enjoyment (psychological domain), their social acceptance, sense of responsibility, social support, and perceived social recognition (social domain), as well as their academic performance (cognitive domain). In line with the previous paragraph, these findings underscore the importance and effectiveness of interventions aimed at promoting PL.

From another perspective, the absence or low level of PL has been associated with negative developmental trajectories, including a lower likelihood of PA participation, reduced perceived competence, increased risk of social isolation, and higher incidence of psychological problems, as shown in research on developmental disorders, among others (Cairney et al., 2019; Öztürk et al., 2023; Pastor-Cisneros et al., 2025). These findings reinforce the need to approach PL as both a pedagogical and public health priority.

Taken together, it becomes evident that fostering PL from early childhood is a crucial objective. However, in order for this development to be effectively planned, supported, and assessed, it is essential to have valid and sensitive instruments that can evaluate PL in all its complexity (Edwards et al., 2017, 2018). Given its multidimensional nature, this represents a significant methodological challenge. For this reason, the design of assessment systems that respect the holistic nature of PL and are applicable in school settings remains a recognized need in the current scientific literature (Edwards et al., 2018).

1.1.4. Methods for assessing Physical Literacy

The growing attention that PL has received has led to a considerable increase in proposed assessment tools. However, the diversity of definitions and philosophical frameworks adopted has hindered the development of validated, consensus-based instruments that capture the complexity of this construct in an integrated manner (Edwards et al., 2017).

Although there is broad agreement on the need to assess PL from a multidimensional perspective, most existing tools present significant limitations. It is common for many instruments to be designed from a partial perspective, focusing only on one or two domains (typically the physical and psychological), without adequately integrating cognitive or social components (Barnett et al., 2023). This methodological limitation, involving a lack of comprehensive assessment, poses challenges for research in school settings and undermines consistency in the advancement of PL studies (Barnett et al., 2019; Edwards et al., 2017).

A recent systematic review (Barnett et al., 2023) identified 14 instruments that meet minimum criteria for validity, reliability, and feasibility for use with school-age populations. Depending on age, different tools are recommended. For younger children, the *Physical Literacy in Children Questionnaire* (PL-C Quest) (Barnett et al., 2022) and *Passport for Life* (Lodewyk, 2019) are considered the most appropriate. For older children and adolescents, the *Canadian Assessment of Physical Literacy* (CAPL-2) (Longmuir et al., 2018) appears to be the most suitable option. Finally, for adolescents, the *Adolescent Physical Literacy Questionnaire* (APLQ) (Mohammadzadeh et al., 2022) and the *Portuguese Physical Literacy Assessment Questionnaire* (PPLA-Q) (Mota et al., 2023) are regarded as the most relevant, as they best represent the four domains. Despite this, the authors conclude that no fully holistic and validated instrument currently exists that integrates the interactions among the domains, particularly in educational settings (Barnett et al., 2023).

One of the most frequently cited limitations in the literature is the restricted capacity to assess the cognitive domain in real-life motor contexts (Cornish et al., 2020; D. B. Robinson & Randall, 2017). As highlighted in the reviews by Barnett et al. (2023) and Jean de Dieu and Zhou (2021), executive functions (e.g., inhibition, sustained attention, working memory, decision-making) are typically measured using isolated tests in laboratory conditions. This prevents observation of their performance in dynamic and functional situations such as active play, sport, or structured motor tasks in Physical Education. This methodological gap is especially relevant when attempting to analyze the joint functioning of the physical and cognitive domains in ecological contexts (Edwards et al., 2018).

The psychological and social domains are generally assessed through questionnaires, as in the case of the PPLA-Q, which allow access to constructs such as motivation, confidence, or perceived competence. Although these instruments also present limitations [e.g., social desirability bias or lack of contextual sensitivity (Mota et al., 2023)], they offer a useful approach for exploring affective and relational aspects within the school environment (Barnett et al., 2022; Dudley et al., 2017).

Feasibility is also a critical issue. Most of the more comprehensive instruments require trained personnel, substantial administration time, and specific equipment, which limits their widespread use in schools with limited resources (Edwards et al., 2018; Robinson & Randall, 2017). In contrast, questionnaires, although more feasible, tend to sacrifice precision or depth in certain domains (Barnett et al., 2023). Thus, finding a balance between comprehensiveness and applicability remains an ongoing challenge.

In this regard, there is a clear need to advance toward functional and context-sensitive assessment models that respect the multidimensionality of PL. This methodological gap is particularly evident in the lack of tools capable of simultaneously assessing the physical and cognitive domains in ecological contexts. This limitation is addressed in the first study of this dissertation, through the design and validation of an innovative dual-task-based instrument that enables integrated observation of physical and cognitive performance (CP) in real motor situations.

While it is necessary to develop tools that allow for the integrated assessment of the various PL domains, it is equally important to explore how these dimensions interact with other key indicators of child development, such as academic achievement (AA) and CP. Understanding these relationships can provide deeper insight into the relevance of PL in school settings and serve as a foundation for more inclusive and personalized educational models.

1.1.4.1. A person-centered approach to assessing Physical Literacy

Most studies analyzing the different dimensions of PL and their relationship with other indicators of child development (e.g., CP or AA) have traditionally employed variable-centered analytical approaches (Cairney et al., 2019). These methods are highly valuable for identifying general trends and statistical associations across populations, and have greatly contributed to the consolidation of our current understanding of the latent dimensions involved, such as MC, PA participation, or motivation (Magnusson, 2003). However, when dealing with complex and multidimensional constructs such as PL and child development, it can also be beneficial to complement these approaches with person-centered methodologies.

Unlike variable-centered models, which focus on relations between variables, person-centered approaches aim to identify subgroups of individuals who share similar patterns across multiple dimensions. In doing so, they allow for the detection of more integrated profiles that better reflect the dynamic and interactive nature of PL (Magnusson, 2003). Rather than opposing approaches, both perspectives should be seen as complementary. This integrated perspective is particularly relevant when trying to understand how the domains of PL interact and manifest in real-life developmental trajectories (Estevan & Barnett, 2018).

Person-centered approaches have gained increasing relevance in research on Physical Education and motor development (Bardid et al., 2016; De Meester et al., 2016), although this is not a novel concept, as it has been present in research for many years (Bergman, 1988). This methodological approach is based on the principle that individuals do not develop in the same way, and that their characteristics interact differently in each person, resulting in specific configurations of functioning (Bergman & Magnusson, 1997; Estevan & Barnett, 2018). From this perspective, the focus is not so much on the relationship between isolated variables, but rather on identifying patterns or profiles of characteristics that coexist within groups of individuals with similar developmental trajectories (Valentini et al., 2018).

When applied to PL, the person-centered approach allows for the identification of student profiles characterized by different combinations of domain development (i.e., physical, psychological, social, and cognitive). These profiles offer a more accurate representation of educational reality by recognizing the diversity of ways in which students experience and develop their PL. Furthermore, they make it possible to examine how specific configurations are associated with meaningful outcomes such as CP, AA, or PA engagement (Estevan, García-Massó, et al., 2019). In this way, the person-centered approach provides a more representative view of PL.

1.2. COGNITIVE PERFORMANCE AND ACADEMIC ACHIEVEMENT

1.2.1. Cognitive performance

The term "cognition" refers to the set of mental processes that contribute to perception, memory, intellect, and action (Donnelly et al., 2016). Its early development is essential for adaptation and learning. Cognitive development during childhood is a complex and dynamic process, characterized by the progressive acquisition of mental abilities that enable children to understand, interpret, and act upon their environment (Blair, 2002; Lyon et al., 1996). These abilities include functions such as attention, memory, language, perception, reasoning, and executive control (Diamond, 2013). During the early years of life, the child's brain undergoes a stage of heightened synaptic plasticity, in which environmental experiences — especially those related to play, exploration, and movement — play a crucial role in the maturation of the neural circuits that support these cognitive functions (Diamond, 2013; Donnelly et al., 2016).

Among the various cognitive functions, executive functions have received particular attention due to their central role in self-regulation and school learning (Cortés Pascual et al., 2019; Latzman et al., 2010; Samuels et al., 2016). Executive functions include processes such as working memory, inhibition of automatic responses, sustained attention, planning, and cognitive flexibility (Best, 2010). These functions, which rely heavily on the development of the prefrontal cortex, are considered critical for behavioral adaptation and academic success in childhood (Donnelly et al., 2016;

Haapala, 2013). Table 1 presents different aspects of life that benefit from the development of executive functions. Understanding their development and the factors that enhance them is essential for designing effective educational interventions. Given the broad impact of these functions across multiple domains of life, their connection to school performance deserves specific attention.

Table 1. Benefits of executive function development across different areas of life. Adapted from Diamond (2013).

Life aspects	Impact of Executive Functions
Mental health	Executive functions are impaired in many mental disorders, including: addictions, Attention Deficit Hyperactivity Disorder, conduct disorder, depression, obsessive-compulsive disorder, schizophrenia
Physical health	Weaker executive functions are associated with obesity, overeating, substance abuse, and poor treatment adherence
Quality of life	Individuals with stronger executive functions tend to enjoy a higher quality of life
School readiness	Executive functions are more important for school readiness than IQ or early reading and math skills
Academic achievement	Executive functions predict math and reading competence throughout the school years
Work success	Poor executive functions are linked to lower productivity and difficulties in finding and maintaining employment
Marital harmony	A partner with poor executive functions may be more difficult to get along with, less reliable, and/or more prone to impulsive behavior
Public safety	Deficits in executive functions lead to social problems such as delinquency, reckless behavior, violence, and emotional outbursts

1.2.2.Academic achievement

According to Donnelly et al. (2016), the extent to which a student achieves their educational goals is referred to as AA. It is considered a key indicator of overall development and future well-being (Santana et al., 2017). The connection between AA and executive functions is well supported in the literature (Becker et al., 2014;

Cortés Pascual et al., 2019; Dias et al., 2022; Latzman et al., 2010; Röthlisberger et al., 2013; Samuels et al., 2016). These mental processes enable children to manage relevant information, self-regulate their behavior, and adapt to changing contexts — skills that are essential for school learning (Haapala, 2013; Santana et al., 2017). Learning involves acquiring and reorganizing knowledge, skills, and values — processes that require adequate cognitive and emotional self-regulation (Donnelly et al., 2016).

In recent years, numerous studies have explored the role of executive functions as a foundation for learning and school adaptation. Various findings highlight that these abilities are essential for meeting academic demands, such as paying attention, planning, or self-regulating, especially in complex and changing environments (Pesce et al., 2013; Samuels et al., 2016). Thus, executive functions not only facilitate the acquisition of new knowledge but also contribute to the development of adaptive behavior in childhood (Blair, 2002; Lyon et al., 1996) and to the establishment of appropriate social behaviors across the lifespan (Diamond, 2013).

Moreover, evidence has shown that executive functions predict performance in various areas of the school curriculum, beyond general intelligence or prior knowledge, both in childhood and adolescence (Becker et al., 2014; Cortés Pascual et al., 2019; Dias et al., 2022; Latzman et al., 2010; Purpura et al., 2017; Röthlisberger et al., 2013; Samuels et al., 2016). In particular, cognitive tasks involving processes such as inhibition and working memory have been found to be closely related to achievement in mathematics and reading (Blair & Razza, 2007; van der Sluis et al., 2007). These findings suggest that AA does not rely solely on the acquisition of content, but also on the efficiency of the mental processes that manage, monitor, and optimize knowledge acquisition (Best et al., 2011). In this sense, understanding the factors that influence cognitive development can offer new pathways for enhancing educational success from a more holistic perspective.

1.2.3. Methods for assessing cognitive performance and academic achievement

Understanding how CP and AA are assessed is essential for accurately interpreting the relationship between these two constructs. General cognitive ability, also known as intelligence, is defined as a general capacity to reason, plan, solve problems, and learn from experience (Deary, 2013; Deary et al., 2007). It has historically been considered a key predictor of educational success (Malanchini et al., 2020).

The most widely used tests for measuring cognitive ability, such as the Wechsler scales for children and adults, assess multiple dimensions of cognitive functioning, including verbal ability, non-verbal reasoning, memory, and processing speed, and provide a global index of intelligence quotient (Irby & Floyd, 2013; Wechsler, 1949). This index shows notable stability from childhood through adulthood (Deary et al., 2000) and predicts important educational, occupational, and life outcomes (Colom & Flores-Mendoza, 2007; Strenze, 2007). However, these are instruments that require individual administration, trained personnel, and a considerable amount of time, which may limit their use in field studies or in educational settings with limited resources.

To overcome these limitations and to assess specific cognitive processes in a more appropiate and targeted manner, a number of instruments have been developed to evaluate distinct executive functions. For example, the Digit Span test assesses working memory and sustained attention through the ordered repetition of numerical sequences (Loughan et al., 2012). Another tool, the Corsi Blocks test, evaluates visuospatial working memory by requiring participants to reproduce sequences of spatially presented blocks (Kessels et al., 2000). Finally, the Stroop test is a classic tool for analyzing executive functions such as selective attention, cognitive inhibition, mental flexibility, and processing speed (Shen et al., 2021), by presenting stimuli in which the meaning of the word and its color do not match, requiring the participant to inhibit automatic responses. These tools offer a fast, simple, and effective way to assess various executive functions.

Academic performance, in turn, can be assessed using various methods. Standardized tests measure specific skills such as reading fluency, comprehension, or problem-solving (Donnelly et al., 2016; Kaufman et al., 2012), while school grades or teacher evaluations provide a more contextual and cumulative view of students' academic performance (Kaufman et al., 2012). Despite their methodological differences, both forms of assessment show high correlations with each other, especially when used complementarily (Rimfeld et al., 2019).

Nevertheless, the overreliance on standardized testing as the sole measure of achievement has been questioned, as such tests may not adequately capture the diversity of students' abilities, learning styles, or sociocultural contexts (Rimfeld et al., 2019). From a broader perspective, it is important to recognize that both cognitive and academic performance are influenced by multiple, interacting factors. Therefore, assessment systems should not be limited to measuring outcomes alone, but should also consider the contexts, resources, and processes involved. This perspective aligns with integrative frameworks such as the PL approach, which emphasizes the importance of incorporating physical, psychological, social, and cognitive dimensions, in addition to their interactions, in order to more fully understand students' development and learning.

1.2.4. Factors influencing cognitive performance and academic achievement

CP and AA in childhood are shaped by a wide variety of factors that interact in complex ways. The scientific literature has identified numerous variables that can influence learning and development processes, either directly or indirectly.

On the physical level, regular PA participation (Esteban-Cornejo et al., 2015; Fedewa & Ahn, 2011; Sember et al., 2020; Zhang et al., 2024), maintaining good physical fitness (Ruiz-Ariza et al., 2017; Van Waelvelde et al., 2020) — particularly CRF (Álvarez-Bueno et al., 2020; de Bruijn et al., 2019) and speed and agility (Fernandes et al., 2016; Ruiz-Ariza et al., 2017) — as well as the development of MC (Bao et al., 2024; de Bruijn et al., 2019; Malambo et al., 2022; Ruiz-Ariza et al., 2017; van der Fels et al., 2015) have been shown to exert a positive influence on cognitive functioning. These elements enhance the efficiency of mental processes involved in attention, memory, and self-regulation, all of which are essential for school learning.

From the psychological dimension, key variables include intrinsic motivation (Filgona et al., 2020), perceived competence (De Meester et al., 2020; Salvatierra-Calderón et al., 2024), self-efficacy, emotional regulation, and the satisfaction of basic psychological needs (Reeve & Lee, 2019; Ryan & Deci, 2017). These factors promote active engagement in academic tasks, strengthen persistence in the face of challenges, and are associated with a positive attitude toward learning.

In the social domain, perceived support from peers, teachers, and families, as well as classroom climate and group cohesion, also play an important role (Aranbarri et al., 2023; Costa-Cordella et al., 2021; Drago et al., 2020). These factors help create emotionally safe environments, increase participation, and reduce academic stress, thereby positively influencing students' cognitive and academic performance.

In addition, various contextual and structural factors have been shown to hold significant explanatory power over CP and AA. These include family socioeconomic status, parents' educational level, access to educational resources, and the amount of time dedicated to extracurricular activities (Costa et al., 2024; Lima et al., 2022; Rodríguez-Hernández et al., 2020). Such factors directly influence learning opportunities as well as students' academic expectations and trajectories. Moreover, other lifestyle-related aspects, such as diet quality and sleep habits, have been identified as key contributors to cognitive development and school performance, especially during childhood (Jirout et al., 2019).

However, while all these factors contribute to cognitive development and AA, it is particularly important to highlight that many of them are explicitly integrated into the construct of PL. Therefore, the next chapter will explore this relationship in greater depth, focusing specifically on how the different domains of PL interact with cognitive and academic performance, and examining the scientific evidence that supports this holistic approach to child development.

1.3. PHYSICAL LITERACY AND ACADEMIC ACHIEVEMENT

As discussed in the previous section, cognitive and academic performance in childhood is shaped by a wide range of physical, psychological, social, and contextual factors. Many of these factors, particularly those related to PA participation, motivation, self-perceptions, and social support, are integral components of the PL construct. From this perspective, PL offers a comprehensive view of the multiple variables that influence academic performance, providing an inclusive and innovative framework.

Various components of PL have been positively associated with indicators of school achievement. In fact, high levels of intrinsic motivation, perceived competence (De Meester et al., 2020; Spessato et al., 2013; Zahra et al., 2010), and social support (Bizumic et al., 2009; Crosnoe et al., 2004; O'Malley et al., 2015; Reynolds et al., 2017) (all of which are included in the psychological and social domains of PL) have been shown to promote students' active engagement in the learning process, as well as their ability to manage the cognitive demands of the school environment. However, these domains have traditionally been examined in isolation, which has limited our overall understanding of the phenomenon. Current evidence suggests that studying these factors in a fragmented way hinders the identification of consistent patterns and more complex mechanisms of influence (Cairney et al., 2016).

To address this limitation, PL offers a theoretical and methodological framework that allows childhood development to be approached from a holistic perspective (Cairney et al., 2019). From this integrative view, it becomes relevant to ask how the different domains that comprise PL combine into specific profiles, and how these configurations are associated with AA and CP. A person-centered approach thus enables the identification of interaction patterns among domains and the analysis of how these configurations relate to academic and cognitive outcomes. This is precisely the focus of the second study presented in this dissertation. The aim is to gain a richer and more context-sensitive understanding of learning in order to lay the groundwork for designing educational interventions tailored to each student's needs and strengths.

Nevertheless, while this analytical strategy helps identify which profiles are linked to better performance, it remains necessary to explore the mechanisms that explain these relationships. Among all the domains that make up PL, the physical domain has been the most extensively studied in relation to CP and AA (de Bruijn et al., 2019; Esteban-Cornejo et al., 2015; Ruiz-Ariza et al., 2017; Singh et al., 2019). Physical competence within this domain has been described as an individual's ability to develop proficiency in performing motor skills, as well as the capacity to perform them at varying intensities and durations (Robinson & Randall, 2017). MC, physical fitness, and regular PA participation represent key aspects of this domain and have been associated with significant benefits across multiple areas of child development, including cognition and AA (Haapala, 2013). Therefore, the following sections will examine in greater depth how these variables relate to AA and CP, and which mechanisms may underlie these associations.

1.3.1.Motor competence

The concept of MC has been defined in multiple ways over time. It is a broad term intended to describe goal-directed human movement (Robinson et al., 2015). This term encompasses several related concepts that have emerged over the years to describe essentially the same idea, such as motor performance, fundamental movement skills, motor proficiency, or motor coordination (Stodden et al., 2008). MC includes both the execution of motor skills (e.g., running, jumping, throwing) and the integration and application of those skills across diverse contexts. A definition of MC provided by Utesh and Bardid (2019) in the Dictionary of Sport Psychology describes it as a latent construct related to proficiency in performing fundamental movement skills, as well as the underlying mechanisms (e.g., motor control or coordination) required for daily life activities and participation in more complex physical activities. Thus, in the context of PL, locomotor skills, object control, and balance (Gallahue, 2012) are all represented within the domain of MC.

Childhood represents a critical period for the development of MC (Goodway et al., 2019). Improvements in MC during early years facilitate participation in PA, as active play and sports typically require a certain level of competence in fundamental movement skills (Lubans et al., 2010). Though, there are multiple factors that can either hinder or support proper development during childhood and adolescence, including biological, environmental, and contextual elements (e.g., home environment, school, culture, and psychological and social influences) (Robinson et al., 2015). Therefore, promoting MC requires careful consideration of all these factors.

The benefits associated with MC are numerous. Indeed, MC has been linked to improvements in physiological characteristics [e.g., Body Mass Index (BMI), physical fitness], psychological aspects (e.g., self-concept, perceived competence), and behavioral outcomes (e.g., participation levels, sedentary behavior) in children (Cattuzzo et al., 2016; De Meester et al., 2020; Lubans et al., 2010; Robinson et al., 2015; Santos et al., 2021). Promoting MC at an early age can thus help foster a lasting active lifestyle, encourage motivation toward PA, and support the development of a positive self-concept (Cattuzzo et al., 2016; Stodden et al., 2008).

1.3.1.1. The relationship between motor competence and academic achievement

Over the past decades, the relationship between MC and AA has attracted increasing interest, particularly in the context of primary education. MC has been shown to not only reflect children's physical development, but also to be involved in cognitive processes that are fundamental to learning. Lopes et al. (2013) outline the potential biological, psychological, and social mechanisms that may help explain this relationship. Among these, they highlight that coordinative exercise activates brain regions such as the cerebellum (associated with motor functions) and the frontal lobes, which are involved in attention, working memory, verbal learning, and self-regulation. From this perspective, MC is conceived as an integrated capacity that both influences and is influenced by cognitive, emotional, and social functions involved in holistic childhood development.

Several experimental studies, such as that of Budde et al. (2008), have shown that motor coordination exercises lead to significant improvements in cognitive functions such as attention and concentration, likely due to the activation of neural networks involved in executive control. Along these lines, research by Cameron et al. (2016) highlights consistent associations between fine and gross motor skills and executive functions such as working memory, inhibitory control, and sustained attention. These processes are, in turn, essential for academic performance in subjects like mathematics and reading. Moreover, when children master basic motor tasks (such as writing legibly or coordinating movements during desk work), they require fewer attentional resources for execution, allowing them to allocate greater cognitive effort to academic demands. This "resource release" effect helps explain why MC can serve as a facilitator, or even a compensatory factor, in learning contexts (Cameron et al., 2016).

Accordingly, numerous studies have sought to examine the link between MC and AA in greater depth, providing evidence through various approaches and methodologies. Lopes et al. (2013), for example, associate the promotion of MC in early childhood not only with better academic outcomes, but also with higher levels of cognitive development, executive functioning, and school readiness. In line with this, the study by Cameron et al. (2016) emphasizes that motor skills are integrated with cognitive and visuospatial processes within the school context, directly influencing key behaviors for learning. In a broader review, McDonald et al. (2018) analyzed the associations among PA, physical fitness, cognition, and AA. The authors reaffirm the existence of positive and significant associations between various components of MC and AA, especially in mathematics and reading. For instance, they highlight the relationship between fine motor skills and performance in math and reading during the early school years, as well as the role of upper-limb coordination, agility, and speed as predictors of overall academic performance.

In this line, the systematic review by Wang and Wang (2024) confirms that both fine and gross motor skills are positively associated with overall AA. While gross motor skills showed a stronger relationship with language performance and general academic outcomes, fine motor skills demonstrated a consistent association with success in mathematics, reading, writing, spelling, and language, with over 60% empirical support in all cases. These findings reinforce the hypothesis that motor skills contribute to school learning through multiple pathways, involving perceptual, cognitive, and self-regulatory processes.

Traditionally, the explanation for the MC–AA relationship has focused on a primarily cognitive pathway: it is assumed that improvements in MC enhance executive functions (e.g., attention, working memory, inhibitory control), which in turn lead to better school performance. While this explanation is both valid and essential, it may be incomplete in that it fails to capture the integrated nature of child development.

The PL framework encourages a more holistic perspective, suggesting that the mechanisms linking movement and learning are not exclusively cognitive. It is plausible that other domains of PL (i.e., psychological and social) also play a role in this relationship. Therefore, further investigation is warranted to examine how the different components of PL, taken together, contribute to the connection between MC and AA.

1.3.2. Physical fitness

Physical fitness has been defined as an individual's capacity to perform physical activities or tasks, and it is closely related to both present and future health (Pate et al., 2013). It is a multifaceted concept that includes physical and physiological components such as cardiorespiratory and musculoskeletal fitness (e.g., endurance and muscular strength, respectively), as well as flexibility (Ortega et al., 2008). Developing physical fitness enables children to engage in PA efficiently by optimizing endurance and strength, reducing the risk of illness, fatigue, and stress, and promoting an active lifestyle while decreasing sedentary behavior (Ortega et al., 2008; Schindler et al., 2008).

Among all the components of this construct, CRF stands out as the most commonly assessed health-related factor and one that is systematically associated with MC (Ortega et al., 2008; Stodden et al., 2014). Specifically, CRF refers to the ability of the circulatory and respiratory systems to deliver oxygen to working muscles, ensuring resistance to fatigue and energy production during PA (Raghuveer et al., 2020). Thus, during childhood and adolescence, CRF levels have been shown to be indicators not only of physical health (Cattuzzo et al., 2016; Stodden et al., 2014), but also of mental health (Lubans et al., 2016) and AA (Santana et al., 2017).

1.3.2.1. The relationship between cardiorespiratory fitness and academic achievement

The connection between CRF and AA is primarily grounded in strong evidence linking PA and good aerobic fitness with brain health (Chaddock et al., 2012). Neuroscientific research has demonstrated that regular exercise induces both structural and functional changes in the brain. In their systematic review, Marques et al. (2018) synthesized the pathways through which these benefits occur. According to the authors, engaging in PA and maintaining good CRF can modify brain structure and function through three main pathways:

- Structurally, changes have been observed in the thickness of grey matter in specific cortical regions, as well as improvements in the integrity of white matter tracts that support executive functioning.

- At the level of plasticity, exercise induces neuronal changes that strengthen signaling capacity and enhance communication across brain networks.

- Cognitively, direct improvements have been reported in higher-order mental processes such as attention, memory, and most notably executive function.

Together, these structural, functional, and cognitive benefits create a brain environment more conducive to learning, which may help explain observed improvements in academic performance (Chaddock et al., 2015; Marques et al., 2018).

Building on this biological foundation, epidemiological evidence also confirms this association at the behavioral level (Álvarez-Bueno et al., 2020; Lang et al., 2018; Marques et al., 2018). Multiple systematic reviews and meta-analyses converge on the same conclusion: there is a positive, significant, and consistent relationship between CRF and AA in both childhood and adolescence.

In Marques et al.'s own review (2018), all 22 studies examining the relationship between CRF and AA broadly supported the beneficial effect of CRF on students' academic performance. Furthermore, they highlighted that maintaining or improving CRF over time is associated with more favorable academic trajectories. Notably, none of the reviewed studies found detrimental relationships between CRF and academic performance (Marques et al., 2018).

A similar pattern was found in the review by Lang et al. (2018), where performance on the 20-meter shuttle run test was not only positively associated with AA, but also with psychosocial health and perceived physical competence. Based on these findings, the authors concluded that CRF, when assessed through a simple and feasible test, can serve as a powerful indicator of the overall health of children and adolescents, linking physiological, cognitive, and psychological domains (Lang et al., 2018). This perspective reinforces the AM framework, by showing how a component of the physical domain (i.e., CRF) is interwoven with outcomes in other domains.

Finally, Álvarez-Bueno et al. (2020) reached similar conclusions in their systematic review and meta-analysis. They not only reaffirmed the association between CRF and AA across various academic domains (e.g., mathematics, language, and overall scores), but also highlighted its persistence in longitudinal studies, suggesting that the effect remains stable over time.

The convergence of neurobiological and epidemiological evidence thus establishes an unequivocal link between CRF and academic performance. However, the fact that CRF is also associated with psychosocial variables suggests that the connection with AA may not be exclusively direct and physiological. This opens the possibility of indirect or mediating mechanisms. Therefore, in order to build a comprehensive explanatory model, it is essential to investigate the potential role of other factors from the psychological and social domains in this complex relationship.

1.3.3.Physical activity

It has been demonstrated that the components of PL can influence the practice of PA, both in the present and in the future (Cairney et al., 2019). Specifically, both MC (Ortega-Benaventet al., 2024) and CRF (Franklin et al., 2022) are closely linked to this construct. Engaging in PA plays a fundamental role in the health and well-being of both young and adult populations. The WHO has set clear objectives for improving child health and preventing diseases related to physical inactivity (World Health Organization, 2010). Among these are engaging in moderate to vigorous PA (MVPA) and limiting sedentary time; however, current levels of PA among young people remain below the recommended thresholds (Ricci et al., 2020; Villanueva et al., 2016).

The established guidelines recommend at least 60 minutes of MVPA per day for individuals aged 5 to 17 years (Bull et al., 2020). Moreover, the PA should be primarily aerobic in nature, equivalent to approximately 11,500 steps per day (Adams et al., 2013). Promoting PL in children may not only increase their regular PA levels in order to meet the recommended guidelines, but also improve their bone health, support healthy muscle growth and development, and enhance their motor, psychological, and cognitive development (Janssen & LeBlanc, 2010).

1.3.3.1. The relationship between physical activity and academic achievement

Various studies have demonstrated that PA, particularly when implemented regularly and consistently, has a positive impact on AA in children and adolescents. In a global review, Barbosa et al. (2020) analyzed 41 systematic reviews and meta-analyses. The authors found that chronic PA, such as school-based aerobic exercise programs, is associated with small to moderate improvements in areas such as attention, memory, and overall school performance. These effects, although not always uniform, reinforce the idea that movement does not interfere with learning but can act as a catalyst for it. This body of evidence supports the structured integration of PA into the school environment as a strategy not only to promote physical health but also to enhance students' cognitive development and academic success.

The relationship between PA and AA is sustained by multiple mechanisms that can be classified into three levels: biological, cognitive, and psycho-emotional (Mandolesi et al., 2018). At the biological level, regular exercise increases the release of neurotrophins (e.g., BDNF, IGF-1, and VEGF), which act as neuronal growth factors (Hötting et al., 2016), promoting neurogenesis, synaptogenesis, and improved brain perfusion, especially in key regions such as the hippocampus and the prefrontal cortex. At the cognitive level, these structural and functional adaptations translate into improvements in mental processes fundamental to learning, such as sustained attention, working memory, processing speed, and cognitive flexibility (Hötting & Röder, 2013). Finally, on a psycho-emotional level, PA regulates neurotransmitters such as dopamine, serotonin (Korb et al., 2010), and endorphins (Fuss et al., 2015), reducing levels of anxiety, stress, and mental fatigue, thereby creating a more favorable emotional environment for learning. Together, these mechanisms explain why physically active students tend to show better academic performance, both in terms of mental processes and emotional readiness for learning.

1.3.4. Factors involved in the relationship between motor competence, cardiorespiratory fitness, and academic achievement

Although numerous studies have attempted to analyze the relationship between MC, CRF, and AA, the results remain diverse and, at times, contradictory. On the one hand, it has been shown that executive functions act as relevant mediators between CRF and both academic and CP, facilitating processes such as attention, planning, and problem-solving (van der Niet et al., 2014; Visier-Alfonso et al., 2020; Yangüez et al., 2024). On the other hand, the specific role of MC in this association has been less explored, particularly regarding gross motor skills (Cadoret et al., 2018; Schmidt et al., 2017).

In addition, regular PA may influence this relationship. Given that both MC and CRF can be enhanced through adequate levels of PA, and that PA itself has demonstrated direct effects on cognitive functioning, it is plausible that the amount, frequency, and quality of PA play a relevant role in the association between physical capacities and academic performance. Recent studies have suggested that the context, motivation toward PA, and regular engagement in physically demanding activities may amplify or attenuate the impact of physical capacities on school performance (Álvarez-Bueno et al., 2020; Donnelly et al., 2016). Therefore, it is pertinent to consider its potential role within this relational framework.

Despite the growing interest in understanding the influence of physical variables on AA, studies that jointly analyze MC, CRF, and their relationship with school performance remain scarce. This methodological limitation hinders a comprehensive understanding of the phenomenon and suggests that not all factors involved in this complex interaction have yet been identified (Haapala, 2013). One relevant line of research has focused on executive functions as potential mediating mechanisms, especially in relation to CRF. However, findings remain inconsistent.

For instance, some studies focusing exclusively on MC (Cadoret et al., 2018) have found a significant mediation of executive functions in its link to AA. The same applies to research analyzing only CRF (van der Niet et al., 2014; Yangüez et al., 2024). Nevertheless, when both physical variables are examined simultaneously, the results become more complex: in some cases, cognitive mediation only appears in the relationship between MC and AA (Schmidt et al., 2017), while in others, a serial and interrelated contribution of MC, CRF, and executive functions to academic outcomes is observed (Fernández-Sánchez et al., 2024).

These inconsistencies highlight that cognitive processes, while relevant, may not be sufficient to fully explain the relationship between physical capacities and AA. This opens the door to considering the involvement of other mechanisms that may operate in parallel or in a complementary manner to these processes in shaping this relationship.

1.3.4.1. The role of the psychological domain

In recent years, several studies have begun to explore the role of psychological factors as potential mediating mechanisms between physical performance and AA. A recent systematic review (Visier-Alfonso et al., 2022) expands the traditional cognition-centered approach by considering mental well-being, including variables such as self-concept, motivation, and emotional control, as mediating elements in the relationship between PA and AA. This shift in perspective highlights the relevance of affective-motivational processes as indirect pathways linking PA participation with school performance.

Complementarily, the study by Salvatierra-Calderón et al. (2024) focuses on the relationship between CRF and cognitive functions, emphasizing the importance of subjective perceptions of competence. Their results show that it is not only the objective level of CRF that influences CP, but also the personal perception of being fit, which in turn affects perceived cognitive competence. This chain of relationships suggests that the effects of MC and CRF on AA may be mediated by psychological constructs such as self-efficacy, physical and academic self-concept, or autonomous motivation.

These findings suggest that psychological processes may play a key role in mediating the relationship between physical competence (as a core element of PL) and AA, thereby offering a deeper understanding of this association. Consequently, it is meaningful to broaden the scope and investigate such mechanisms that might be involved in this connection, such as motivation, self-concept, or perceived competence. In this context, the PL framework gains particular relevance, as it provides an integrative perspective that encompasses not only the physical domain, but also the affective-motivational, cognitive, and social dimensions of development.

Given the holistic nature of child development and the multidimensional character of self-concept (Marsh & Martin, 2011; Palenzuela-Luis et al., 2022), it becomes pertinent to explore the extent to which perceptions of physical capacities influence perceived academic competence. If this connection is confirmed, it could establish a theoretical and practical bridge between the physical and academic domains, helping to understand how a positive experience with movement and PA not only promotes health and active engagement, but also contributes to school performance by strengthening students' identity and self-efficacy.

Perceived motor competence

One of the key elements within the psychological domain is perceived MC, understood as the self-assessment an individual makes regarding their ability to perform motor skills. This perception not only influences the individual's motor self-esteem but also their willingness to participate in physical activities (Estevan & Barnett, 2018). Children who perceive themselves as competent in motor terms tend to engage more frequently and enthusiastically in a wide range of motor experiences (Ortega-Benaventet al., 2024), which in turn supports improvements in both their actual MC and CRF (De Meester et al., 2020; Robinson et al., 2015).

From a broader perspective, perceived MC can act as a precursor to other dimensions of self-concept, particularly within the physical domain (Marsh & Martin, 2011; Palenzuela-Luis et al., 2022). This relationship suggests that promoting a positive perception of one's own MC not only encourages participation in PA but may also strengthen students' overall self-image, with potential repercussions for their motivation, well-being, and AA.

Perceived physical fitness

Beyond the execution of specific motor skills, children also develop a broader perception of their physical fitness. This psychological construct encompasses how they evaluate themselves in aspects such as endurance, strength, speed, or flexibility, and it has been linked to both MC and CRF (Henning et al., 2022; Jaakkola et al., 2019). The perception of physical fitness is part of the general physical self-concept, which also includes dimensions such as body appearance, overall coordination, and perceived sport competence (Estevan et al., 2018; Tietjens et al., 2018) (Figure 3).

There is evidence that a positive perception of one's physical condition can serve as a driving force for maintaining PA and consolidating active lifestyles (Estevan & García-Massó, 2024). In fact, perceived MC may be considered a key antecedent of this more global perception, as confidence in one's own motor skills contributes to forming a more favorable image of general physical fitness (Babic et al., 2014; Estevan et al., 2018; Lohbeck et al., 2021). In turn, this positive perception influences other psychological variables such as self-confidence or autonomous motivation (Henning et al., 2022; Timler et al., 2019), which may act as facilitators of a stronger academic self-perception (Denche-Zamorano et al., 2023).

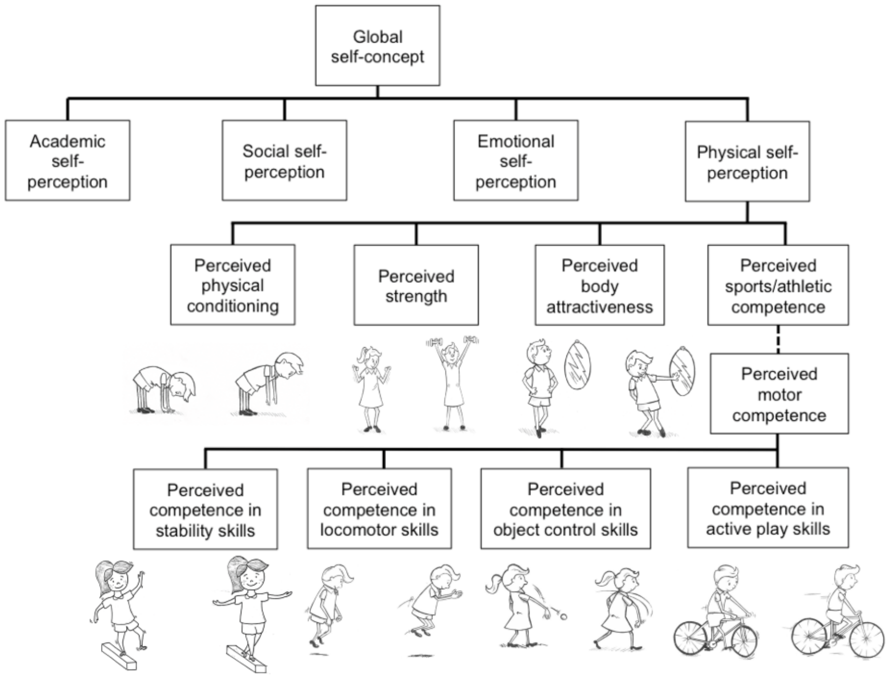

Figure 3. Representation of the hierarchical and multidimensional model of global self-concept, including pictographic descriptions in each domain of physical self-perception. Adapted from Estevan and Barnett (2018).

Motivation

Another key factor in this network of relationships is motivation toward PA, especially when it is autonomous. Autonomous motivation refers to engagement in an activity driven by personal interest, enjoyment, or internal value, and contrasts with controlled motivation, which is guided by external pressures or rewards (Deci & Ryan, 2008; Ryan & Deci, 2020).

Evidence shows that children with higher perceived MC and physical condition tend to develop more autonomous motivation toward PA (Gillison et al., 2011;

Menescardi et al., 2022; Menescardi et al., 2023; Sebire et al., 2013). This type of motivation not only promotes adherence to PA but also contributes to a more positive emotional experience, enhancing students' overall well-being. Conversely, those with a negative perception of their physical condition may engage in PA out of obligation or external pressure, which, in the medium term, could affect their self-concept and their connection to Physical Education and the school environment in general (Henning et al., 2022).

Autonomous motivation has also been linked to the development of personal competencies such as persistence, self-regulation, and goal-setting, all of which are relevant for academic performance. Therefore, fostering positive perceptions of the physical self may act as a catalyst for intrinsic motivation, with benefits not only in the physical domain but also in the academic one.

Perceived Physical Literacy

Both autonomous motivation towards PA and perceived MC are key components in the construction of physical self-concept. However, these indicators do not fully capture the multidimensional nature of physical development (Ortega-Benaventet al., 2024). In contrast, perceived PL reflects not only physical skills and competencies, but also affective, social, and cognitive aspects that shape motor experiences. This self-perception of being "physically literate" may act as a protective factor against demotivation, disengagement from PA, or negative school experiences. Furthermore, high perceived PL can strengthen students' global self-efficacy and their resilience when facing academic challenges, promoting a balanced development across physical, emotional, and cognitive domains (Cairney et al., 2019).

From this perspective, investigating the role of different elements within the psychological domain in the relationship between MC, CRF, and AA is not only relevant but necessary to understand how physical well-being is transformed into psychological resources that support learning and school adjustment.

1.3.4.2. Psychological perceptions as mediators between physical capacities and academic achievement

Throughout this section, it has been shown that MC and CRF, as core dimensions of the physical domain of PL, have been associated with benefits in students' cognitive and academic development. Likewise, robust evidence has been reviewed concerning the role of both PL and its associated domains in psychological well-being, motivation, and active participation in school settings. However, it has also been noted that the mechanisms explaining the relationship between physical capacities and AA remain not fully established. While executive functions have often been regarded as primary mediators, the findings in this line of research are inconsistent and do not fully capture the complexity of the phenomenon. This limitation has led to growing interest in exploring the role of psychological variables as potential mediators that could offer a more comprehensive and integrated understanding.

Therefore, the third empirical study of this thesis aims to explore whether psychological self-perceptions in the physical and cognitive domains help explain the link between physical capacities and AA in childhood. Specifically, the objective is to analyze the association between physical competence (i.e., MC and CRF) and AA. In addition, the mediating role of physical and academic self-perceptions in the relationship between MC and CRF with AA is examined. Finally, the study seeks to determine to what extent the inclusion of PA in the model enhances its explanatory power, considering its key contribution to the development of both MC and CRF (Lubans et al., 2010; Ortega et al., 2008; L. E. Robinson et al., 2015; Schindler et al., 2008).

1.4. OBJECTIVES AND HYPOTHESES

Based on the general theoretical framework presented above, this section outlines the objectives and hypotheses of the current research project, which is organized into three complementary studies.

General hypothesis and objective

Within the conceptual framework of PL, it is proposed that the physical domain is positively associated with cognitive and AA in childhood, and that this relationship may vary depending on contextual demands (such as cognitively loaded tasks), individual characteristics (multidimensional profiles), as well as psychological factors such as self-perceptions and motivation.

To test this hypothesis, the main objective of this research is formulated as follows: to comprehensively analyze the relationship between physical competence (i.e., MC and CRF) and cognitive and academic performance in childhood, considering the role of contextual factors (e.g., cognitive demands derived from PA and multidimensional profiles) and psychological mechanisms (e.g., self-perceptions and motivation) that may influence this relationship, all within the holistic model of PL.

Specific objectives

Study 1

To design and validate an instrument that allows for the simultaneous assessment of MC and CP in an ecological setting, and to analyze how cognitive demands influence motor performance in school-aged children. Additionally, to identify performance profiles under dual-task conditions and to explore differences in comparison with performance on single tasks.

Our hypothesis is that the introduction of cognitive demands (i.e., dual-task) in the MC test will significantly affect students' motor performance, decreasing their execution compared to the simple motor task. Moreover, it is hypothesized that students will cluster into differentiated profiles based on their combined (i.e., cognitive and motor) performance during the dual-task, and that these profiles will show significant differences in performance on both simple and complex tasks.

Study 2

To identify student profiles based on the interaction among the physical, psychological, and social domains of PL, and to analyze how these profiles relate to cognitive and AA, adopting a person-centered approach.

Our hypothesis is that differentiated student profiles will be identified according to their level of PL, considering the physical, psychological, and social domains. Furthermore, it is hypothesized that these profiles will be differently associated with cognitive and AA, such that those with a more balanced and higher development across the three PL domains will show better outcomes in both areas.

Study 3

To analyze the association between physical capacities (i.e., MC and CRF) and AA, and to examine the mediating role of physical and academic self-perception in this relationship. Additionally, to determine the added value of PA as an explanatory factor for AA.

Our hypothesis is that psychological self-perceptions (i.e., physical and academic) will significantly mediate the relationship between physical capacities and AA, and that including PA levels will enhance the explanatory power of the model.

1.5. STATE OF ART OF STUDY 1

The concept of PL can be defined as the set of social, emotional and cognitive capacities to cooperate and communicate appropriately with the environment. It also requires a holistic commitment including integrated physical capacities in perception, experience, memory, anticipation and decision making (Whitehead, 2001). PL currently refers to motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for engagement in physical activities for life (Cairney et al., 2019; Whitehead, 2019). PL also includes four interconnected domains, i.e., psychological, social, cognitive and physical (Longmuir et al., 2015). Achieving appropriate levels of PL is a fundamental part of developing self-fulfillment, self-confidence and positive self-esteem.

Physical education pays particular attention to MC, which is a key element in the physical PL domain. Although there is a wide variety of tests available to evaluate MC, they do have some limitations (Hulteen et al., 2020). Whereas isolated-based field-motor tests (e.g., the Gross Motor Development Test or the

Körperkoordinations Test for Children) are reliable enough in assessing MC, others are too far removed from the context in which fundamental movement skills are carried out (usually situations in sport that require a combination of skills). Circuit-based field-motor tests emerged as an alternative system of evaluating children's movement skills and their ability to combine simple movements to perform more complex movements, [e.g., the Canadian Agility and Movement Skill Assessment (CAMSA)] (Longmuir et al., 2017). However, as making decisions, which is inherent in practicing sport, is missing in the CAMSA, MC does not seem to be assessed ecologically. Including perception tasks and decision making in the CAMSA test would be an interesting way of evaluating MC in an ecological setting as well as evaluating some of the PL cognitive elements (e.g., perceptual awareness or reasoning).

To date, no test has been devised to concisely assess the cognitive domain. In fact, Cornish et al. (2020) states that the instruments used to measure PL usually focus on fundamental movement skills and are limited in measuring the cognitive domain. It is also suggested that future research should try to explore and develop instruments to assess the cognitive domain holistically (Edwards et al., 2018). It is essential to have tools to assess the cognitive domain objectively to understand motor development and PL holistically (Edwards et al., 2018). Cognitive tests are usually carried out to assess children's executive functions, such as working memory, inhibition and cognitive flexibility (Diamond, 2013). However, these tests are performed in a sedentary context far removed from PA. As the results of these tests may possibly differ from the CP during PA, we therefore considered it would be of interest to develop an instrument capable of evaluating elements in the cognitive domain when carrying out MC tests.

Combining cognitive and physical tasks in the same test seems to be the key to creating a method of ecologically determining PL cognitive level and performance, while dual-tasking (DT) is an already existing paradigm in which motor and cognitive tasks are carried out simultaneously and the effect of the interactions between them on performance are studied (Bustillo-Casero et al., 2017). DT is used in laboratory settings but its usefulness in more ecological environments is still unknown. Tests that include simultaneous motor and cognitive tasks could be used to assess cognitive function and MC ecologically. It is also of interest to design tools that allow PL to be assessed holistically, or at least gradually incorporate multiple domains simultaneously. Using DT to assess both motor and CP in the same field test would be a breakthrough in achieving this goal.

Even though it is important to consider that the interference generated by performing two tasks at the same time may affect the students who are proficient in performing simple tasks and who may not be as proficient in a DT, different interaction patterns have been found between tasks during DT. In these models we find three different theories to explain DT interference (Bonnet & Baudry, 2016; Lacour et al., 2008; Wollesen et al., 2016). These include the cross-domain competition model (two tasks performed simultaneously or in quick succession, requiring the same or overlapping cognitive processes), the U-shaped nonlinear interaction model (the optimal level of task difficulty that allows efficient multitasking, while both easier and more difficult tasks can result in reduced performance), and the prioritization model (faced with multiple tasks, individuals allocate most attention to the most important at a given time while reducing the resources allocated to the lower-priority task). These three models emerged as the outcomes of divergent results in different DT studies (Bonnet & Baudry, 2016; Bustillo-Casero et al., 2019; Lacour et al., 2008; Wollesen et al., 2016). The divergence in the findings could have been the result of the subjects' individual strategies to deal with the DT. In fact, we do not know how factors like age or task difficulty can influence performance during DT (Bustillo-Casero et al., 2017; Marco-Ahulló et al., 2022; Schaefer, 2014).

The aim of this study was thus to design and test a new version of the CAMSA that included decision-based verbal and visual cues (i.e., cognitive CAMSA) to assess both MC and CP, plus the impact of the cognitive load in MC in an ecological setting. To achieve this, the interference in the students' performance in the variables derived from the original CAMSA (i.e., motor skill score, time score, and total score) when performing the cognitive version of the test was first determined. It was thus possible to observe whether the students responded differently when performing the traditional test compared to the cognitive CAMSA in the motor domain. On confirming that not all the students responded in the same way to a DT, the second objective was to establish the student profiles based on the variables derived from the cognitive CAMSA (i.e., cognitive score, motor skill score, and time spent). The third objective was to determine the differences between the performance profiles in single cognitive tasks, single motor tasks, performance during DT, and gender, which would allow us to determine whether the PL cognitive and motor tests using DT aligned with the results of single tests. If we confirmed that different results were obtained in DT and single tasks, it would open up a discussion about the suitability of DT-based tests to assess cognitive and motor performance. DT could thus provide a more ecological assessment and would better represent what actually happens during physical activities and sports.

1.6. STATE OF ART OF STUDY 2

The comprehensive development of children is a crucial area of research for promoting social health and well-being, with CP being a central aspect (Diamond, 2013). The concept of CP involves the capacity to process information, exhibit intelligence and reasoning skills, as well as developing language and memory. These cognitive functions are typically measured through both subjective assessments (i.e., assessed by self-reports or reports from others such as AA or academic self-perception) and objective assessments (i.e., assessed by standardized cognitive tests such as the Stroop, Digit Span tests or math fluency) (Wardle-Pinkston et al., 2019). Fostering and stimulating CP from early childhood can be beneficial for their well-being and mental health (Diamond, 2013; Singh et al., 2019). Formal education, participation in sports and other experiences in social and cultural settings contribute significantly to individuals' progress in CP (Filgona et al., 2020; Owen et al., 2023; Singh et al., 2019). However, not all individuals have access to environments that raise these processes (Yosep et al., 2022). In a constantly changing sociocultural context, it is important to provide a wide range of opportunities for the development of young children's cognitive processes. Achieving this requires a comprehensive understanding of the foundational factors that influence CP in childhood. Previous research has demonstrated that CP is associated with a multitude of factors, including genetics, age, gender, area of residence, socioeconomic status and lifestyle (Malanchini et al., 2020; van Kempen et al., 2012).

PA participation is one factor extensively studied in sports science over the last decades for its influence on CP. Several physical domain factors have been identified as playing a particularly essential role in the influence of CP. Among these factors, PA practice (Esteban-Cornejo et al., 2015; Fedewa & Ahn, 2011; Fernandes et al., 2016), physical fitness (Ruiz-Ariza et al., 2017; Van Waelvelde et al., 2020), and MC (de Bruijn et al., 2019; Malambo et al., 2022; Ruiz-Ariza et al., 2017) emerge as significant elements that warrant consideration. Despite some inconsistencies in the existing evidence, PA has been repeatedly identified as a significant contributing factor to CP development (Álvarez-Bueno et al., 2020; Sember et al., 2020). Physical fitness, for its part, is closely linked to PA, with components like CRF (de Bruijn et al., 2019; Sember et al., 2020) and speed-agility (Fernandes et al., 2016; Ruiz-Ariza et al., 2017) consistently associated with enhanced CP. MC also shows emerging evidence of its relationship with CP (de Bruijn et al., 2019; Malambo et al., 2022; Ruiz-Ariza et al., 2017). A systematic review by van der Fels et al. (2015) revealed a moderate-to-strong association between fine motor skills and visual processing, while bilateral body coordination showed a weak-to-moderate correlation with fluid intelligence. Conversely, Bao et al. (2024) found low associations between gross motor skills components — such as locomotion, object control, and stability — and CP, suggesting that including neuropsychological factors in future studies could provide a deeper understanding of these relationships. However, the findings from experimental studies, particularly those conducted in school settings, remain inconclusive regarding the impact of increasing PA practice on CP. For instance, while Zeng et al. (2017) found that increased PA had a positive impact on executive functioning, language, and AA in four of five randomized controlled trials, Sember et al. (2020) reported minimal improvements in academic performance from PA interventions that lasted a minimum six weeks. These disparate findings suggest that additional factors may influence in this relationship. In this case, the potential moderating effects of PA intensity and instructor on the effects of PA on CP were identified (Sember et al., 2020). Meanwhile, Esteban-Cornejo et al. (2015) proposed that the type of activity and certain psychological factors, such as self-esteem or depression, could also act as mediators in this association. A holistic approach related to PA beyond the physical domain that considers also psychological and social variables appears necessary to gain clearer insights into the connections between PA and CP.

In this regard, different factors from the psychological domain associated with PA, appear to exert a direct or indirect influence on CP. Motivation (Filgona et al., 2020), satisfaction of basic psychological needs (Ryan & Deci, 2017) and self-perceptions (Salvatierra-Calderón et al., 2024), such as perceived competence (De Meester et al., 2020), have been identified as potential elements influencing CP development and have recently been investigated. Positive autonomous motivation — including intrinsic motivation, integrated regulation, and identified regulation — has been associated to regular PA practice (Ng et al., 2012), which may indirectly enhance children's CP by increasing PA levels (Li et al., 2024). However, no studies have explored the direct impact of PA practice motivation on CP. Additionally, Reeve and Lee (Reeve & Lee, 2019) examined the neural basis of basic psychological needs within self-determination theory, finding that satisfying these needs positively correlates with activation in brain regions associated with CP. Similarly, Wang et al. (Wang et al., 2019) showed that in school settings, the satisfaction of basic needs, academic performance, and behavioral engagement are mutually reinforcing, suggesting a complex and dynamic system. Additionally, Zhen et al. (2017) found that competence and relatedness (but not autonomy) directly predict learning engagement, thereby enhancing AA. Lastly, research shows that self-perceptions can play a pivotal role in both PA practice (De Meester et al., 2020) (i.e., physical self-concept and perceived MC) and CP development (Salvatierra-Calderón et al., 2024). In this case, age may play a crucial role in this association, as research has shown that children tend to perceive themselves more realistically as their capacity for self-perception matures (De Meester et al., 2020) due to greater CP development. However, the mechanisms underlying this relationship remain unclear and may vary significantly between individuals (Esteban-Cornejo et al., 2015; Salvatierra-Calderón et al., 2024; Zahra et al., 2010).

Furthermore, given that PA is inherently a social experience, particularly in group settings or team-based activities, it is crucial to examine how social factors related to PA practice may influence CP. Variables such as peer interactions, social support, and group dynamics could significantly contribute to shaping the relationship between PA and CP (Hu et al., 2021; O'Malley et al., 2015; Yosep et al., 2022). Hu et al. (2021) analyzed the social factors in PA participation from the perspective of the social-ecological model and highlighted interpersonal, organizational, community and political factors impacting CP. At the interpersonal and organizational levels, support from friends, parents and teachers emerged as positive predictors of students' participation in PA, alongside school interventions. At the community and policy level, access to safe facilities and safe neighborhoods were key factors in promoting PA among children (Hu et al., 2021). Thus, these social factors may contribute directly to PA practice in childhood and throughout life, and indirectly to CP. Evidence also suggests that certain social elements, like school identity and enjoyment, can positively impact CP development and overall well-being (Bizumic et al., 2009; O'Malley et al., 2015). For instance, O'Malley et al. (2015) identified school climate and sense of identification as key predictors of AA in numeracy and writing.

Understanding that the physical, psychological, and social domains not only impact PA and CP but also interact with one another is essential. Studying them in isolation could provide limited insights, as extreme scores in one factor may positively or negatively influence another. To date, no studies have considered the combined impact of a wide range of physical, psychological, and social variables on CP. This limitation may stem from traditional statistical methods becoming less effective as more independent variables are included. A variable-centered approach, compared to a person-centered method based on multiple input variables, may yield limited evidence when addressing this research gap. Indeed, a previous study employing a person-centered approach using self-organizing maps and clustering to analyze physical and cognitive variables, identified distinct student profiles in dual-task performance with varying CP levels (Montalt-García et al., 2023). These profiles helped to identify specific needs and strengths among students, offering a clearer understanding of how various factors influence their overall development. This highlights that children differ in their performance and responses, and some variable relationships may not be consistent across all profiles. A detailed analysis of how these elements affect CP could provide an overall perspective, enabling interventions and policies to be tailored to specific needs and challenges. The present study aimed to comprehensively explore children's profiles and the intricate relationships between their physical, psychological and social domains and their impact on CP.

1.7. STATE OF ART OF STUDY 3

MC can be defined as a person's capacity to perform different goal-directed movements, generally operationalized through the proficiency in performing fundamental movement skills and the underlying mechanisms (Robinson et al., 2015). This concept encompasses not only the execution of movement skills, such as running, jumping, or throwing, but also the integration and application of these in diverse contexts, thereby facilitating active engagement in PA (Lubans et al., 2010). The development of MC is associated with benefits in multiple domains (physiological, psychological, behavioral (Cattuzzo et al., 2016; De Meester et al., 2020; Lubans et al., 2010; Robinson et al., 2015). During childhood, MC represents a critical factor, establishing a foundation for the development of other abilities/skills and contributing to the well-being of the child (Barnett et al., 2016; Lubans et al., 2010; Robinson et al., 2015). The acquisition of MC during childhood and adolescence can have a significant impact on future lifestyle choices, influencing factors such as self-concept and motivation to engage in PA (Cattuzzo et al., 2016; Stodden et al., 2008).

MC has been historically related to health-related fitness that is a multidimensional concept encompassing five key components: CRF, muscular strength, muscular endurance, flexibility, and body composition (Britton et al., 2020). Health-related fitness enables individuals to perform PA efficiently while optimizing endurance and strength, reducing the risk of disease, fatigue, and stress, and promoting an active lifestyle with minimal sedentary behavior (Ortega et al., 2008; Schindler et al., 2008). The most assessed health-related factor that is consistently associated with MC is CRF (Cattuzzo et al., 2016; Stodden et al., 2014). CRF refers to the capacity of the circulatory and respiratory systems to supply oxygen to our working muscles, thus ensuring resistance to fatigue and energy production during PA practice (Raghuveer et al., 2020). For children and adolescents, CRF levels have been demonstrated to be a prognostic indicator of health outcomes (Cattuzzo et al., 2016; Ross et al., 2016; Stodden et al., 2014), including but not limited to mental health (Lubans et al., 2016) and AA (Santana et al., 2017). Just as the development of MC is fundamental, achieving good levels of CRF is also crucial for the healthy growth and overall development of children.

Another important aspect for children's overall development is AA that refers to their academic performance and success in school (Santana et al., 2017). AA can be assessed through grade point averages, standardized achievement tests, or specific evaluations of key skills such as reading fluency, comprehension, and mathematical problem-solving abilities (Donnelly et al., 2016). In recent years, there has been increasing interest in the relationship between these three variables (i.e., MC, CRF and AA), but investigations combining all three factors are limited (Haapala, 2013). Numerous studies have documented the positive association of CRF with AA in children, often mediated by improvements in high-level cognitive functions as executive functions (Cadoret et al., 2018; van der Niet et al., 2014). However, the role of MC in this relationship remains less explored, particularly for gross motor skills (Schmidt et al., 2017; Wang & Wang, 2024). This gap suggests that additional factors may influence this connection and should be examined to gain a deeper understanding of how and why MC is linked to AA. Furthermore, the results on whether cognitive and especially executive function mediate the associations of MC, CRF or both with AA are mixed. Studies that focus on either MC (Cadoret et al., 2018) or CRF (van der Niet et al., 2014; Yangüez et al., 2024) in isolation report a significant mediation by executive function, whereas studies that investigate both MC and CRF report a mediation by executive function only in the MC-AA relation (Schmidt et al., 2017), or an interrelated contribution by MC, CRF and executive function to AA in a serial fashion (Fernández-Sánchez et al., 2024). These inconsistencies suggest that the relation between MC/CRF and AA cannot be fully explained by cognitive mechanisms and leaves the question open whether other psychological factors beyond those in the cognitive domain might be involved in distinct or common pathways linking CRF and MC to children's academic performance.

Recent systematic review evidence (Visier-Alfonso et al., 2022) expands the focus of the mediated link between performances in the physical and cognitive domain, considering PA as the predictor of academic performance and looking at psychological factors – along with actual CRF and cognitive function – as potential mediators of the PA-AA relationship. This review suggests a mediating role for psychological factors belonging to the mental well-being construct in the relationship between PA and AA. Specifically, factors such as self-concept, emotional control and motivation seem to mediate the aforementioned relationship, suggesting the idea that PA may enhance mental well-being and motivation, which, in turn, could lead to improved (Visier-Alfonso et al., 2022). Also, a recent study (Salvatierra-Calderón et al., 2024) has evaluated the mediating role of psychological factors in the relationship between performances in the physical and cognitive domain but with a narrower focus on the CRF-cognition relationship, thus excluding the correlate of CRF (i.e., PA) and the school outcome of cognitive skills (i.e., AA). Those findings suggest that performances in the physical domain and AA are not directly - or not only directly - related, but their relationship is mediated by the psychological perceptions of being capable in those domains. Indeed, a serial mediation path indicates that actual physical fitness is positively related to the personal perception of being fit which, in turn, is related to the perception of being cognitively fit and, lastly, to actual CP (Salvatierra-Calderón et al., 2024). This approach to psychological intermediary mechanisms between actual performances in the physical and cognitive domains is novel and worthy of being applied to investigate the pattern of still inconsistent and piecemeal evidence of mediators acting in the association of MC and CRF with AA. Specifically, knowing the multidimensional nature of self-concept (Marsh & Martin, 2011; Palenzuela-Luis et al., 2022), if MC and CRF influence the development of physical self-perceptions, and if this, in turn, modulates self-perception of AA, a bridge could be established between the physical and AA domains through the construction of a positive perception of the physical and cognitive-academic self.

As regards the broad range of physical self-perceptions, perceived MC plays a foundational role. Perceived MC refers to an individual's self-evaluation of their MC, which may influence their willingness to engage in PA (Estevan & Barnett, 2018).

Children with high perceived MC are more likely to participate in a variety of physical activities (Ortega-Benaventet al., 2024), which, in turn, enhance both their MC and CRF (De Meester et al., 2020; Robinson et al., 2015). Given the potential influence of perceived MC on other dimensions of self-concept (Marsh & Martin, 2011; Palenzuela-Luis et al., 2022), understanding its role in the MC-AA relationship is a fundamental step toward identifying the psychological mechanisms that might mediate this association.

Expanding beyond the specific perception of competence in performing motor skills, perceived physical fitness emerges as a broader psychological construct that encompasses individuals' perceptions not only of their competence in performing coordinated movements, but also of their endurance, speed, flexibility, and strength. Perceived physical fitness has been shown to be related to both MC and CRF (Henning et al., 2022). Perceived physical fitness is a component of the broader physical self-concept which includes an individual's perception of their physical abilities, encompassing physical appearance, general sportiness, and physical fitness (Estevan et al., 2018; Tietjens et al., 2018). Thus, as for the actual constructs, perceived MC can be considered as a precursor of perceived PF, as greater confidence in one's MC may lead to more positive perceptions of PF, reinforcing engagement in PA (Estevan et al., 2018; Lohbeck et al., 2021). This, in turn, can foster self-confidence and psychological well-being [e.g., autonomous motivation, self-identity (Henning et al., 2022)], both of which may contribute to shaping academic self-perception (Denche-Zamorano et al., 2023).

Furthermore, the development of autonomous motivation for PA is closely linked to one's perceptions of MC and physical fitness (Henning et al., 2022; Menescardi et al., 2022). According to Self-Determination Theory (Ryan & Deci, 2020), motivation exists on a spectrum ranging from autonomous (driven by interest and personal value) to controlled (regulated by external pressures) motivation (Deci & Ryan, 2008). Autonomous motivation towards PA is more likely experienced by children with higher perceived MC (Menescardi et al., 2022; Menescardi et al., 2023) and perceived physical fitness (Sebire et al., 2013), as feeling physically competent fosters intrinsic enjoyment and self-determined engagement in PA (Menescardi et al., 2023). Conversely, children with low perceived physical fitness may engage in PA reluctantly (Henning et al., 2022), driven by external pressures rather than intrinsic enjoyment (Ryan & Deci, 2020) which can negatively impact their motivation over time.

However, the constructs of autonomous motivation to practice PA and perceived ability in tasks that require coordination, endurance, speed, flexibility, and strength do not fully capture the multidimensional nature of physical development (Ortega-Benaventet al., 2024). In contrast, perceived PL offers a more comprehensive framework, integrating motivation, confidence, physical competence, knowledge, and understanding to support lifelong engagement in PA (Cairney et al., 2019; Ortega-Benaventet al., 2024; Whitehead, 2019). Indeed, the perception of being physically literate encompasses psychological, social, and environmental factors that shape an individual's movement experiences (Cairney et al., 2019).

Taken together, existing evidence suggests that the above-described psychological factors pertinent to the physical domain, including children's perception of being competent in motor skills, physically fit, autonomously motivated toward PA and physically literate, are interconnected with children's actual MC and CRF.

Since both MC and CRF, in turn, contribute to AA, but the mechanisms underlying this relationship remain insufficiently understood, children's perceptions of competence in the physical domain emerge as potential mediators that may shape how physical competence influences academic self-perception and performance, integrating existing mediation evidence that is still piecemeal and only partially explanatory. By integrating these constructs in these relationships, a more comprehensive explanatory model can be developed. Given its integrative nature, perceived PL may represent a key mechanism in the MC-AA relationships, as it encapsulates not only the development of motor skills but also the motivational and cognitive dimensions that also underpin long-term academic and physical success.

Thus, the aim of this study was to evaluate whether psychological self-perceptions in the physical and cognitive domain can contribute to explaining why children's physical and academic competence are associated. Specifically, the aim was threefold: (1) to analyze the association between physical competence (MC, CRF) and academic performance (AA); (2) to explore the mediating role played by physical and academic self-perceptions in the associations of MC and CRF with AA; and (Cairney et al., 2019) to determine to what extent incorporating PA into this model enhances the explanation of AA, given the role of PA as a key contributor to the development of MC and CRF.

METHODOLOGY

2. METHODOLOGY

2.1. STUDY DESIGN AND PARTICIPANTS

2.1.1. Study design and participants of Study 1

One hundred and sixty-nine secondary school students (39.3% girls) volunteered to participate during the 2021–2022 academic year in this cross-sectional study. The participants' characteristics can be seen in Table 2. All the participants performed all the tests (i.e., the original CAMSA, cognitive CAMSA, Corsi Block and Digit Span tests). The sample was selected from three secondary schools of urban areas in the province of Valencia near Valencia city (Valencia Community, Spain). Those students with cognitive or physical impairments that prevented them from performing the different tests or that could pose a risk to their health were also invited to participate, but were excluded from the statistical analyses.

The students' parents or guardians provided signed informed consent forms before the study, and the participants gave their assent orally. The procedures conducted in the study were performed in accordance with the Helsinki Declaration, and the study was approved by the Ethical Committee of the University of Valencia (Code 1259844).

Table 2. Participants' sociodemographic characteristics.

Sex	Age (years)	Weight (kg)	Height (m)
Girls	13.07 (0.74)	50.1 (9.95)*	1.59 (0.06)*
Boys	13.3 (1.02)	54.53 (10.9)	1.65 (0.09)
All	13.2 (0.85)	52.5. (10.7)	1.62 (0.08)

*indicate significant differences between girls and boys ($p < 0.05$).

2.1.2. Study design and participants of Study 2

This cross-sectional study was part of the Active Learning in PHYsical Literacy (ALPHYL) study, conducted between 2022 and 2023. The required sample size to conduct the experiment was computed by using the G*Power 3.1 software (University of Düsseldorf, Düsseldorf, Germany). Based on a similar study investigating how student profiles based on MC, muscular fitness and CRF influence educational variables (e.g., mathematical skills) (Jaakkola et al., 2021), it was determined that the effect size to be identified was Cohen's f = 0.272. Using this effect size, a Type I error rate of 0.05, and a Type II error rate of 0.2, a sample size of 152 participants was obtained. Given that previous studies suggest relatively low compliance rates for wearing accelerometers long enough to ensure valid PA measurements (with dropping rates potentially exceeding 50%) (Eckelt et al., 2023; Kolle et al., 2009; Rowlands, 2007), efforts were made to recruit double the minimum required sample size.

Before the study, the families and guardians received an informed consent form, which they were required to sign, and the participants volunteered to participate. The consent rate was 97.3%. The initial sample consisted of two hundred and ninety-five participants, 33.6% of whom were excluded for not meeting the accelerometry requirements (i.e., having, at least, valid data from three working days and one weekend day, with a minimum of 8 hours per day). Additionally, participants with physical or cognitive impairments that prevented them from performing the tests normally (n = 3) were allowed to complete the tests, but their data were excluded from the statistical analyses. Finally, data from one hundred ninety-four fifth-grade children (48.96% girls) with a mean age of 10.61 years (SD = 0.45) were employed in this cross-sectional study. Data collection for this study was conducted from October

7, 2022, to March 24, 2023. All the tests, including the questionnaires and the physical and cognitive tests, were completed by the participants, who were from six schools located in the urban area of the province of Valencia (Valencian Community, Spain). The six participating schools were selected through randomization, with final inclusion based on their agreement and willingness to carry out the necessary assessments. The study procedures were conducted in accordance with the Helsinki Declaration, and the Ethical Committee of the University of Valencia approved the study (Code 1564606).

2.1.3. Study design and participants of Study 3

This cross-sectional study was part of the Active Learning in PHYsical Literacy (ALPHYL) study, conducted between 2022 and 2023. The study design, implementation, and reporting followed the guidelines of the CONSORT statement (Moher et al., 2006) and adhered to the SPIRIT recommendations. Approval for the project was granted by the Ethics Committee of the university of Valencia (Reference Code UV1259844).

A total of 218 fifth-grade children (51.4% girls; M age = 10.53, SD = .36) from six schools in Valencia and its metropolitan area participated. Schools included four public and two private institutions. Written informed consent was obtained from participants' families, and verbal consent was gathered from the children before participation (consent rate 87.8%). Inclusion criteria required signed consent from families and willingness to participate. Exclusion criteria included evident physical or mental difficulties that would hinder the completion of the required measurements. Only typically developing children were included in the analysis.

The required sample size was determined using G*Power 3.1 software (University of Düsseldorf, Düsseldorf, Germany) to ensure adequate statistical power. A priori power analysis for a linear multiple regression model (fixed model, R^2 increase) was conducted with an assumed effect size of $f^2 = .15$ (moderate effect), an alpha level of .05, a power of .95, three tested predictors, and four total predictors. The analysis indicated that a minimum of 119 participants was required. The Institutional Ethical Committee of the University of Valencia approved the study. Written informed consent forms were obtained from parents prior to their children's participation.

2.2. PROCEDURES

2.2.1. Procedures of Study 1

The researchers first contacted the school principals to explain the study and request their participation. The families were informed about the nature of the project and once they had given their written consent, the measurement protocol was carried out. To complete all the tests, the participants performed two experimental sessions separated by at least 24 h. The CAMSA and Corsi Block tests were carried out in one session, while the cognitive CAMSA and Digit Span test were included in the other. The order of the sessions was counterbalanced within the schools to minimize any potential order effects, i.e., whereas the students in one classroom performed the tests in the same order, those in another classroom performed the test in the reverse order (i.e., first the cognitive CAMSA and Digit Span test, followed by the original CAMSA and Corsi Block test).

For the completion of both the cognitive and original CAMSA tests, the students were instructed to complete the assessment as quickly as possible while performing the skills to the best of their MC. In line with the original procedure, two demonstration trials were provided for each participating class. The first demonstration was performed by a research assistant familiar with the CAMSA test, while explaining each skill thoroughly. The second demonstration was performed by the same research assistant to indicate the effort and speed required to carry out the test. Each student performed two familiarization trials and two formal trials, which were coded ad hoc. During the familiarization trials, verbal cues were used only to remind the participants of the next task to be performed, in an attempt to minimize the impact of memory on the task sequence and completion time. These cues consisted of indicating aloud the next task to be performed (e.g., "throw the ball"). The timing began with the command "go" and ended when the participant kicked the soccer ball (Estevan et al., 2023). The time required to perform the original CAMSA test ranged from 14 to 47 s, and the mean completion time being 22.73 ± 5.57 s. During the assessment trials, no feedback was provided on the task performance and no attempt was made to encourage task performance or affect the learner's performance in any way. In accordance with the protocol (Longmuir et al., 2017), the score of the best attempt was used to calculate the MC scores.

The cognitive CAMSA followed the same procedure as the original CAMSA in terms of the students' performance. In this case, the time taken to perform this test ranged from 15 to 53 s (average 25.36 ± 7.05 s). Both the original and cognitive CAMSA were performed in the school yard. There were some slight modifications in the cognitive CAMSA related to participants' CP during motor performance as decision-making events and minor adjustments to the test equipment (i.e., differences in hoop colors, placing throwing targets, and variations in shooting at goal). The cognitive tests were performed in silent classroom using a laptop and open-source software Psychology Experiment Building Language 2 (Mueller & Piper, 2014). The participants received a series of instructions provided automatically by the program for the completion of the tasks, while any doubts were answered by the researcher. The cognitive tasks were conceptualized as measures of executive functions, as in previous studies (Cooper et al., 2016; Pontifex et al., 2019).

2.2.2. Procedures of Study 2

The study commenced by contacting the schools and their principals, explaining the research objectives and requesting their collaboration. After obtaining consent from the families, measurements were taken over the course of a single week in each school. During this week, data were collected on participants' daily PA levels using accelerometers, alongside written questionnaires, physical tests, and cognitive tests. AA data was obtained from the school principals who provided students' academic grades. The research team supervised all the tests.

The questionnaires were filled in the children's regular classroom after an explanatory introduction. Questionnaires were projected onto a whiteboard, and a research assistant read each item aloud. Two additional research assistants supervised the entire process providing support to the participants when required. All the questions were answered during two 45-minute sessions held on different days within the same week. Following the questionnaires, the mathematical fluency test was administered to the class group and timed by the researchers. Cognitive tests were subsequently then conducted in a quiet environment on computers under the supervision of the researchers. Finally, physical tests were conducted in two sessions, either in the school gym or schoolyard, during two Physical Education lessons. Researchers provided explanations and demonstrations before each group of students performed them. All tests were managed by researchers.

2.2.2.1. Self-organizing maps analysis procedure

Participants were classified using the SOM process, an unsupervised artificial neural network that generates profiles based on input variable similarities. Daily MVPA, CRF, actual MC, BMI%, perceived MC, perceived PL, intrinsic motivation, identified motivation, perceived PA participation, perceived competence in PE, perceived relatedness in PE, physical self-concept, school enjoyment, social identity and task-involving climate were included as input variables. Matlab R2022b software (MathWorks Inc., Natick, MA, USA) and the SOM toolbox (version 2.0 beta; Laboratory of computer and information science, Helsinki University of Technology, Helsinki, Finland) for Matlab were used to compute the SOM analysis.

The SOM analysis involved the following training process: first, the construction of a neuron network per input variable, whose size was determined by the number of cases included in the data set (i.e., 194 participants) and the proportion of the two main eigenvalues of the data set. This resulted in a neural network consisting of 12 x 6 neurons (height x width). Values were then assigned to each neuron for all input variables in both random and linear initialization, while the values of the initially assigned neurons were modified according to sequential and batch training algorithms. A visual representation of the SOM training process is shown in Figure 4. This flowchart illustrates the key steps in constructing and training the neural network, as well as the iterative adjustments of the neuronal weights.

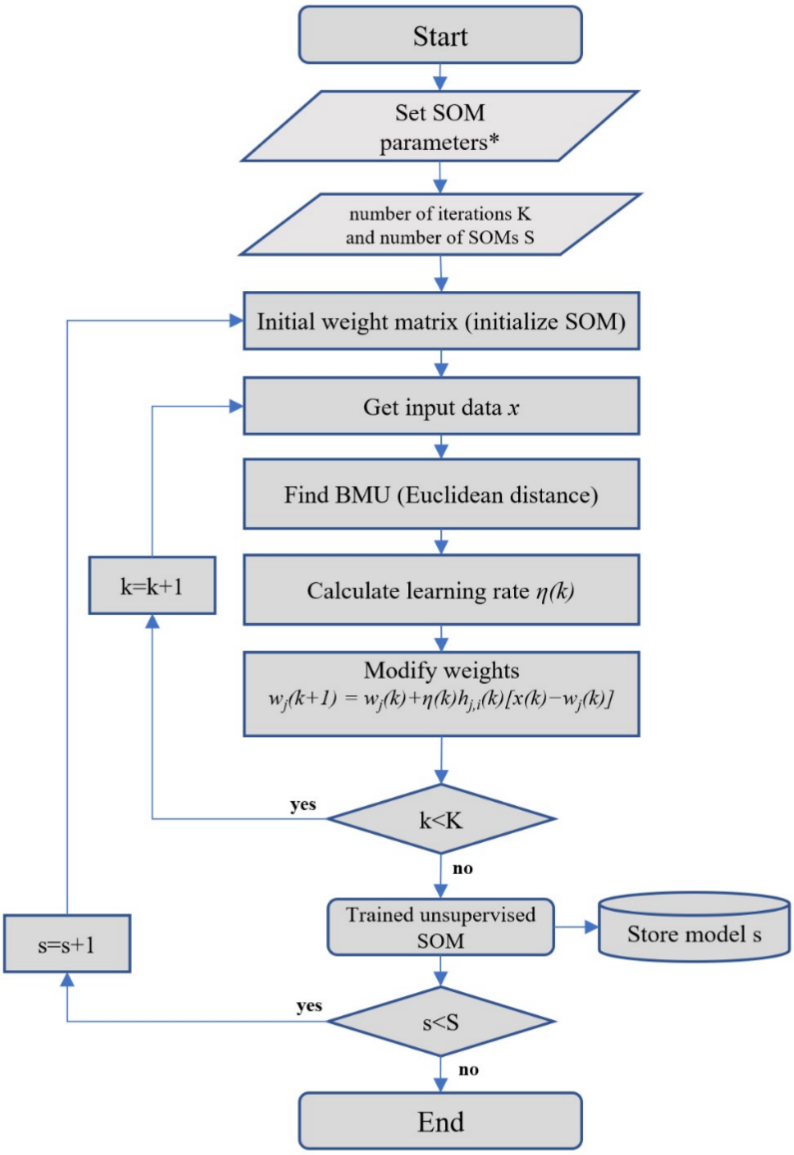

Figure 4. Flowchart for the unsupervised SOM algorithm. Modified from Seifert et al. (56) with permission. Here, k denotes time, $x(k)$ is an input vector randomly drawn from the input data set at time k, $h_{j,i}$ denotes the neighborhood function around the winner unit j and $\eta(k)$ the learning rate at time k.

Various factors influence the adjustment of the neuronal weights during each iteration of the training phase. Initially, an input vector (i.e., a participant) is introduced to the network. The neurons within the lattice engage in a 'competition' by comparing the Euclidean distance of their weight vector with the values of the input vector. The goal is to minimize the Euclidean distance between the weight vector and the input vector, aligning the winning neuron with its associated input cases. All the neurons in the lattice then adjust their weight values to approach the values of the input vector. The extent of adaptation is influenced by two processes: the learning ratio and the neighbor function. The former is initially high and gradually diminishes throughout the training process. The latter dictates the adaptation of both the winning neuron and the surrounding neurons. The magnitude of adaptation is inversely linked to the distance between the neuron and the winner. This iterative process continues until the training process is completed.

The final analysis depends on a random procedure, including the initialization and entry order of the input vector. To find the best solution, the process was repeated 100 times. A total of 1600 SOMs were obtained from two different training methods, four neighborhood functions, and two initialization methods (i.e., $100 \times 2 \times 4 \times 2$). This number of iterations was selected as it provides a sufficient balance between computational efficiency and the level of convergence necessary for robust results, minimizing the risk of underfitting while allowing the map to capture meaningful patterns in the data. Stability was assessed by monitoring the consistency of the cluster configurations across iterations, ensuring that the profiles identified remained similar after repeated runs. The map with the minimum error was selected by calculating the product of quantization and topographic errors.

The k-means method was used to categorize neurons into broader groups based on the characteristics of the input variables. It is important to note that the input data in this case consisted of the neural weights derived from the SOM analysis and not the subjects' values. The number of clusters ranged from 2 to 10 to prevent an excessive number of profiles. The Davies–Bouldin index was used to evaluate the quality of the clustering configuration and to determine the optimal number of clusters. This index measures the average similarity ratio of each cluster with its nearest cluster, where lower values indicate greater distinctness and separation. In this study, the cluster configuration with the lowest Davies–Bouldin index was chosen, as it indicated the highest separation between profiles and minimized within-cluster variance, supporting the reliability of the selected clusters in representing distinct student profiles. These clusters were used to describe the characteristics of the physical, social, cognitive and psychological dimensions in the students analyzed.

To interpret the maps, all the subjects in a neuron must be considered to share certain characteristics (i.e., input variable values). Each participant (input case) is placed in a specific neuron according to its input variable values at the end of the SOM training process. The maps represent a network of neurons in which each neuron is a hexagon. Between the three dimensions shown, the x- and y-axes represent the topographical situation of each neuron, with the nearest neurons having similar weight values (i.e., input variable values) and the most distant neurons having the most different weight vectors. The remaining dimension is represented by the color of the map, which indicates the weight value of each neuron in the network for each specific input variable.

2.2.3. Procedures of Study 3

Data collection was completed over one week per school. Written questionnaires were used to assess self-perceptions and self-reported PA. Field-based tests were used to assess MC and CRF levels. Students' academic grades were obtained from teachers. Daily PA levels were captured via accelerometers.

Questionnaires were administered in two 45-minute sessions on separate days. Cronbach's α determined internal consistency of all questionnaires: α = .50–.69 (acceptable), .70–.89 (good), ≥.90 (excellent) (Hair et al., 2010). Physical tests were conducted during Physical Education lessons, either in the gym or playground, across two sessions. Weight and height were also recorded. Researchers demonstrated each test beforehand and supervised all sessions to ensure standardization. Accelerometers were distributed and fitted by the research team, and participants were instructed in their correct use to ensure data quality.

2.3. MEASUREMENTS

2.3.1. Measurements of Study 1

2.3.1.1. Cognitive single tests

The Digit Span test, adapted from Wechsler (1949), evaluates working memory and consists of remembering a sequence of numbers presented to the participants and repeating it in the same order (i.e., Digit Span Forward). Since the digital version of the test was used, the numbers were displayed for 1 s on a laptop screen, with a 1-s interval before the next number. The subjects then had to repeat the complete sequence on the laptop. The length of the sequence of numbers starts at three digits and is gradually increased. Two attempts can be made to repeat the numbers. The test is ended when a participant fails both attempts or when they reach the maximum length of 10 numbers. The total number of correct sequences and the longest correctly recalled numerical sequence (i.e., Block Span) were taken as the test outputs. This test has shown moderately high reliability in children aged 6–12 years old (Alloway et al., 2008; Flanagan et al., 2011).

The Corsi Block test, based on the Digit Span test (Kessels et al., 2000) was designed to evaluate visuospatial working memory and consists of remembering a sequence of ordered blocks that appear on a computer screen. The procedure steps included (i) nine blocks in pseudorandom positions; (ii) one block is illuminated during 1 s; (iii) a transient period of 1 s between the stimuli; (iv) second block is illuminated; (v) the procedure continues until the number of blocks reach the maximum sequence length; (vi) the subjects indicate the illuminated blocks by clicking on them with the mouse in the correct order. Two familiarization sequences were first performed, in which three blocks were illuminated, after which the test started with a sequence of two blocks. As in the Digit Span test, the participants were allowed two attempts at each sequence. If they failed both attempts or reached the maximum block sequence of nine blocks the test was ended. The scores obtained were the longest correctly recalled sequence (Block Span), the number of correct attempts and the memory span [minimum sequence length (i.e., 2), added to the number of correct attempts, divided by the number of trials in each sequence length (i.e., 2)].

2.3.1.2. Motor competence

The CAMSA consists of a series of seven movement skills that are completed in a continuous sequence (Menescardi et al., 2022). These skills include three two-footed jumps, sliding along a 3-m distance, returning, catching, and throwing a ball at a wall-mounted target 5 m away, skipping 5 m, performing a one-footed hop in and out of six hoops, and kicking a ball between two cones 5 m apart. The assessment of the children's performance in the CAMSA involves two key criteria: the time required to complete the circuit (product-based) and the quality of the movement pattern executed or the motor skill score (process-based). The time taken to complete the circuit is recorded and transformed into a point score, known as the time score, ranging from 1 to 14 (Longmuir et al., 2017). Higher values indicate a shorter time taken to complete the circuit. The quality of movement is assessed by 14 skill performance criteria, with one point awarded for each criterion completed correctly, resulting in the skill score (Longmuir et al., 2017). Combining the product and process scores, a total CAMSA score of 28 points is obtained (Longmuir et al., 2017). The best score of two trials is considered for evaluation. The CAMSA has been validated in Spain among students in Primary and Compulsory Secondary Education, as described in Menescardi et al. (2022).

2.3.1.3. Simultaneous motor competence and cognitive performance

The Cognitive CAMSA was based on the original version of the test with the same motor skills. The changes included were related to the CP of the participants during the motor performance, with some minor changes to the test equipment including: (i) the three hoops on the left were yellow and the three on the right were blue, (ii) there were two throwing targets in front of the participants with one slightly to the left and the other to the right, and (iii) there were two goal posts, one with yellow cones and the other with blue (Figure 5).

Four decision making events were included in the cognitive assessment: (i) before beginning, the researcher showed a blue or yellow card and the subjects performed the three two-footed jumps inside the hoops of the other color, with 0 or 1 point for a fail or correct performance, respectively; (ii) during the sliding test, the researcher gave some simple numbers to be added before throwing either at the right-hand target if the result was even or at the left-hand target if it was odd, with either a 0 or 1 point for a fail or correct performances respectively; (iii) in skipping, the researcher indicated two numbers to the participants, the first referring to the hoop they should use to start the next motor test (i.e., one-footed jumps) and the second indicated the last hoop in the activity, with 0, 1, or 2 points according to two fails, or to one or two correct performances, respectively; and (iv) after the one-footed jumps, the researcher showed a yellow or blue card and the participants had to kick the ball at the color not shown, with a 0 or 1 point score according to a fail or one or two correct performances, respectively. The cognitive score (from 0 to 5) was the total score, i.e., 0 if no decisions were taken correctly and 5 if all the decisions were correct.

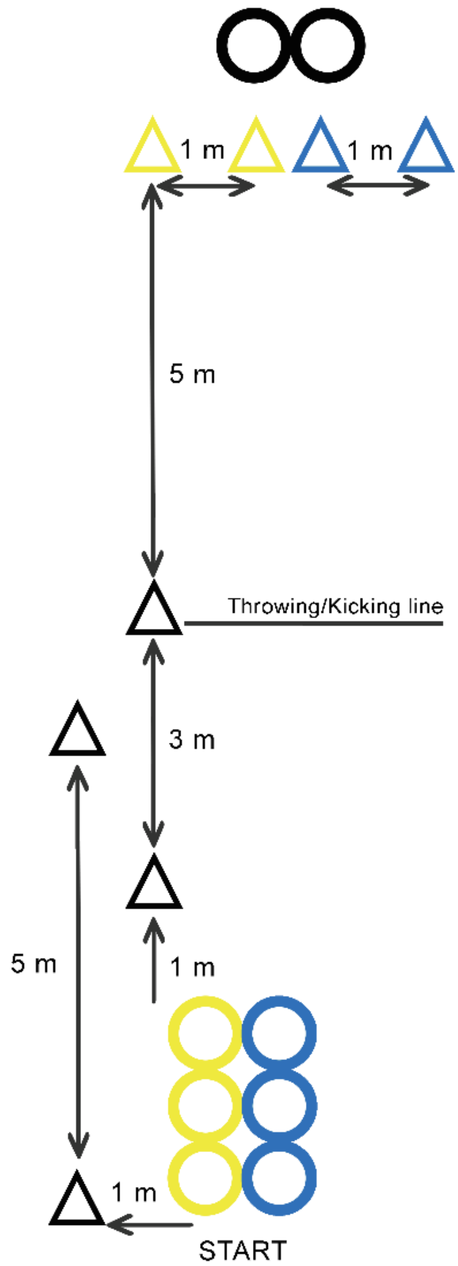

Figure 5. Cognitive CAMSA schedule.

2.3.2.Measurements of Study 2

2.3.2.1. Daily physical activity.

Participants' daily movements (PA and sedentary behavior) were recorded by accelerometers (ActiGraph wGT3X-BT model), which have been shown to be reliable and valid for use in children (Evenson et al., 2008). The students were instructed in their use and wore them for 8 consecutive days. To ensure data validity, a criterion was set requiring at least of three working days and one weekend day with a minimum of 8 hours of accelerometer recording per day. The 8 hours did not need to be registered continuously. The data was analyzed on Matlab R2022b software (MathWorks Inc., Natick, MA, USA).

The vertical axis accelerometer records were initially collected at 15-second intervals and then consolidated into 60-second periods. Segments with 20 or more consecutive minutes of 0 counts were identified, indicating the periods when the participants were not using the device. These data segments were excluded from the subsequent analysis. Thresholds were applied to categorize the minute-by-minute PA intensity (38). Three intensity levels were defined: sedentary (≤100 counts/min), light (≤2295 counts/min) and moderate-to-vigorous (>2295 counts/min).

2.3.2.2. Self-reported physical, social and psychological factors.

Questions were selected from nine different questionnaires, while the input variables in the SOM were based on a prior analysis (non-published data). Table 3 gives the validation references, questionnaires used, and variables analyzed by each scale as regards the various factors related to the students' physical, social and psychological domains.

Table 3. Details of the self-reported questionnaires used in the study according to the domain.

Reference	Questionnaire	Variable	Domain
Menescardi et al. (2022)	Physical Activity Questionnaire for Children (PAQ-C). This questionnaire has demonstrated good validity [χ^2 (20) = 33.583; CFI = 0.98; RMSEA = 0.04; SRMR = 0.03] and reliability (α = 0.73) in previous studies.	Self-Reported PA	Physical
Estevan et al. (2021)	Pictorial scale of Perceived Movement Skill Competence (PMSC). This questionnaire has demonstrated robust structural validity [χ^2 = 29.50; df = 14, p < .01; RMSEA = 0.035; SRMR = 0.020; CFI = 0.989; TLI = 0.983] and reliability, including internal consistency (α > 0.70) and test-retest reliability (intraclass correlation coefficient > 0.70).	Perceived motor competence	Psychological
Ortega-Benavent et al. (2024)	Physical Literacy for Children Questionnaire (PL-C Quest). This questionnaire has proved good structural validity [χ^2 (219) = 304.366; CFI = .92; RMSEA = .04; SRMR = .06], while its reliability has been shown to be strong with internal consistency values (α = .84; ω = .83) and test-retest reliability (r = .84).	Perceived physical literacy	
Menescardi et al. (2022)	Behavioural Regulation Exercise Questionnaire (BREQ). The psychometric properties of this questionnaire indicate satisfactory validity [χ^2 (38) = 61.489; CFI = 0.97; RMSEA = 0.04; SRMR = 0.04] and reliability, with Cronbach's alpha values ranging from 0.54 to 0.72.	Intrinsic motivation Identified motivation	
Sebire et al. (2013)	Basic psychological needs satisfaction within a PE setting. Evidence supports the strong validity of this instrument [χ^2 (99) = 255.75; CFI = 0.95; RMSEA = 0.052; SRMR = 0.04]. Reliability was acceptable, with Cronbach's alpha value of 0.82 for competence subscale.	BPN competence	
Estevan et al. (2019)	The pictorial scale of Physical Self-Concept in Children (P-PSC-C). This questionnaire has demonstrated good structural validity [χ^2 (9) = 29.8; CFI = 0.99; RMSEA = 0.055; SRMR = 0.046], acceptable internal consistency (α = .74) and test-retest reliability (ICC ranging from .47 to .77).	Physical self-concept	
Sebire et al. (2013)	Basic psychological needs satisfaction within a PE setting. Reliability was acceptable for relatedness subscale, with Cronbach's alpha value of 0.81.	BPN relatedness	Social
Castillo et al. (2001)	Intrinsic Satisfaction Classroom Scale (ISC). This questionnaire has proven to be both valid [χ^2(13) = 66, p < .01; df = 5.09; RMSR = .03; GFI = .98; AGFI = .96; CFI = .98] and reliable (α = .8).	School enjoyment	
Bruner and Benson (2018)	Social Identity Questionnaire for Physical Education/Sport (SIQS). Previous studies have demonstrated the validity [χ^2 (18) = 43.52; CFI = 0.99; TLI = 0.98; RMSEA = 0.04; SRMR = 0.02] and reliability (ω = .89) of this questionnaire.	Social identity	
Castillo et al. (2020); Newton et al. (2000)	Learning Climate Questionnaire. Validity [χ^2 (341) = 711.5; CFI = 0.9; RMSEA = 0.054] and reliability (α = .87) of this questionnaire have been well-established in previous research.	Task-involving climate	

2.3.2.3. Cognitive performance.

Cognitive data were collected to evaluate students' actual and perceived CP using objective and subjective instruments, respectively. Subjective CP was assessed through a self-report on language and mathematics competence, adapted from the NEPS matrix test (Schnittjer & Gerken, 2018) scored on a 5-point Likert scale. A mathematical fluency test (Woodcock et al., 2001) and two cognitive tests were administered to objectively measure the CP. The math test assessed the ability to perform 160 simple mathematical operations of addition, subtraction, and multiplication) as quickly as possible. The Digit Span test and the Stroop test were used as individual cognitive tests. The assessment of AA was based on the final grades provided by the schools for the entire academic year. The consistent grading system used across all participating schools ensured a uniform scoring approach. The schools provided scores ranging from 0 (i.e., worst academic performance) to 5 (i.e., best academic performance) for each participant and subject. To obtain a comprehensive score for each participant, the average grade across the school subjects was computed. As trimester evaluations are not conducted in these schools, the final grades represent the cumulative performance across the full academic year.

2.3.2.4. Digit Span test.

An adapted computer version of the Digit Span test was used to evaluate working memory using the Psychology Experiment Building Language 2 software (Mueller & Piper, 2014). The participants were required to recall a sequence of numbers and repeat them in the same order. The digital version of the test displayed numbers on a laptop screen for 1 second, followed by a 1-second interval before the next number. The participants then repeated the entire sequence on the laptop. The sequence length started at three digits and increased progressively, with participants allowed two attempts to repeat the numbers. The test concluded when a participant either failed both attempts or reached the maximum length of 10 numbers. The test results comprised the total number of correct sequences and the longest correctly recalled number sequence (i.e., block width). The Digit Span test has shown moderately high reliability in children (Loughan et al., 2012).

2.3.2.5. Stroop test

An adapted computer version of the Victoria Stroop test, employing the Psychology Experiment Building Language 2 software (Mueller & Piper, 2014), was used to evaluate various aspects of executive functions, including selective attention, cognitive inhibition, cognitive flexibility and information processing speed (Shen et al., 2021). The test consisted of three stages, each with four rows of six items, including at least one item in red, blue, yellow and green per row. The participants were required to scan the items in the rows from left to right and indicate the color of each item on the laptop keyboard. The initial dot task displayed colored dots as the items, while the second, the neutral word task, presented common words displayed in color. The third, known as the color word task, involved identifying the colors that did not match their names. The variables obtained from this task included (a) the completion time per round, (b) total responses per round, (c) accuracy in identifying colors and words, and (d) correct identification of colors and words.

2.3.2.6. Physical test.

Three key measures were used in the physical tests. First, the CAMSA was employed. This test is based on a circuit-based field test to measure actual MC. This test combined product- and process-oriented measures of fundamental movement skills (Menescardi et al., 2022). The second physical test used was the Progressive Aerobic Cardiovascular Endurance Run proposed by Morrow et al. (2010). This test allows to measure CRF level. In third place, children's weight and height were assessed to calculate their BMI percentiles, adjusted for gender and age, following Kuczmarski et al. (2002).

2.3.3.Measurements of Study 3

2.3.3.1. Psychological elements

Perceived motor competence

Perceived MC was evaluated using the Spanish version of the Pictorial Scale of Perceived Movement Skill Competence (Estevan, Molina-García, et al., 2019; Johnson et al., 2016). The questionnaire comprises 13 pictographic motor skills (e.g., running, galloping, hopping, jumping). For each, participants rated their competence on a 4-point Likert scale (1 = lowest, 4 = highest), yielding a total score from 13 to 52: Higher scores indicate greater perceived MC. Reliability was excellent (α = .90).

Perceived physical fitness

Perceived physical fitness was measured with the Spanish version of the Physical Self-Concept in Children Scale (Estevan et al., 2018; Tietjens et al., 2018). The scale comprises seven items representing key dimensions of physical self-concept. These are physical fitness (five items: strength, endurance, speed, flexibility, and coordination), general sportiness (one item), and physical appearance (one item). Each item uses a two-step dichotomous choice format, wherein children initially select which of two depicted children most closely aligns with their own self-perception (e.g., the child who is competent or less competent in the given item). In the second step, they refine their initial selection by indicating the extent to which it applies (e.g., "really good" or "pretty good" for the competent child, or "sort of good" or "not so good" for the less competent child). Scores range from 7 to 28. Only the five-items fitness subscale was used to compute perceived PF. Reliability was good (α = .75).

Self-determined motivation for physical activity

Motivational regulations were assessed using a Spanish version of the Behavioural Regulation in Exercise Questionnaire (Menescardi et al., 2022; Sebire et al., 2013). The scale includes 12 items on a five-point Likert scale, which ranges from (1 = "not true for me" to 5 = "very true for me"), covering intrinsic, identified, introjected, and external regulation (3 items each). A Relative Autonomy Index was computed combining the scores of the four subscales to reflect self-determined motivation for PA. Subscales demonstrated acceptable to good reliability (α = .50–.73).

Perception of Physical Literacy

Perception of PL was assessed using the Spanish version of the Physical Literacy in Children Questionnaire (Barnett et al., 2022; Ortega-Benavent, Menescardi, Romero-Martínez, et al., 2024). The instrument contains 30 items across four domains: physical (12 items), psychological (7 items), social (4 items), and cognitive (7 items). Each item uses a two-stage dichotomous choice procedure. Participants first select one of two illustrated scenarios reflecting different PL levels, then rate their choice on a 4-point scale (1 = "not very good," to 4 = "very good"). Total scores range from 30 to 120, with higher scores indicating a stronger perceived PL. Reliability was excellent (α = .91).

Self-perception of academic achievement

Self-perception of AA was assessed using three items adapted from validated sources: One item from the Health Behavior in School-aged Children (Castillo et al., 2003) evaluating general academic performance, alongside two from the NEPS Matrix Test (Schnittjer & Gerken, 2018) assessing self-perceived performance in mathematics and language. All three items used a 5-point Likert scale ranging from 1 (“very poor” or “much worse than peers”) to 5 (“very good” or “much better than peers”).

2.3.3.2. Field-based tests

Motor competence

MC was assessed using the CAMSA (Longmuir et al., 2017), adapted and validated for Spanish children (Menescardi, et al., 2022). The test consists of seven motor tasks: bipedal jumping (2 points), lateral movement (3 points), catching (1 point), overhand throw (2 points), skipping (2 points), one-foot jumping (2 points) and kicking (2 points). Each skill is scored on process criteria (0 = performed incorrectly to 1 = performed correctly), with a maximum possible process score of 14 points. Product criteria assess the time taken to complete the circuit, converted into a score inversely proportional to time, ranging from 1 to 14. The total score combines the process and product scores, with a maximum of 28 points. Before testing, participants observed two demonstrations (slow-paced with instruction and fast-paced with high quality execution). Each participant completed two familiarization trials followed by two assessment trials with the best score being used.

Cardiorespiratory fitness

CRF was assessed using the 20-metre Progressive Aerobic Cardiovascular Endurance Run, a multistage aerobic capacity test designed to assess aerobic fitness in children and adolescents from the FitnessGram battery (Morrow et al., 2010). Participants ran back and forth according to audio signals, with the number of completed laps representing their final score.

2.3.3.3. Academic grades

Academic grades were provided by schools. The assessment system was consistent across all schools. Marks were standardized in a 0-to-5 scale. The average score across all subjects was used as the overall AA indicator.

2.3.3.4. Physical activity

Self-reported physical activity

Self-reported PA was measured using the Spanish version of the Physical Activity Questionnaire for Children (Crocker et al., 2004; Manchola-Gonzalez et al., 2017). This 9-item questionnaire assesses PA during various times across the previous seven days (e.g., physical education classes, recess, weekends) using a 5-point Likert scale (1 = low activity to 5 = high activity). An additional item screened for children unable to participate in PA that week. This instrument showed good reliability (α = .83).

Accelerometry

PA levels were objectively measured using ActiGraph wGT3X-BT accelerometers (Evenson et al., 2008), worn on the waist for eight consecutive days. Valid data required at least three weekdays and one weekend day, with a minimum of eight hours of recording per day (Benítez-Porres et al., 2016). Non-continuous wear time was permitted, provided that the daily wear time criterion was met. Data were sampled in 15-second epochs and grouped into 60-second intervals. Periods of more than 20 minutes with zero counts were treated as non-wear time. Thresholds for activity intensity were applied to classify PA into three categories: sedentary behavior (≤ 100 counts per minute), light activity (101–2295 counts per minute), and MVPA (> 2295 counts per minute). Data were analyzed using MATLAB R2022b (MathWorks Inc., Natick, MA, USA).

Self-reported PA captures individuals' perceptions of weekly activity, including low-intensity and diverse movement patterns (Marasso et al., 2021). Given that children with higher MC tend to report greater engagement in physical activities (Montalt-García et al., 2025), self-reported PA may be influenced by perceived competence, potentially leading to biased estimations. In contrast, MVPA from accelerometry provides an objective quantification of movement intensity and duration, aligning more directly with CRF, as higher-intensity activities are known to contribute significantly to its development (Aadland et al., 2020). However, a common limitation of MVPA measurement is participant dropout due to insufficient valid wear time, which can reduce the sample size and impact statistical power (Marasso et al., 2021). By combining both PA measurements, this study accounts for distinct behavioural dimensions and strengthens the interpretation of PA's influence on AA (Marasso et al., 2021; Skender et al., 2016).

2.3.3.5. Covariates

In the statistical model, several covariates were incorporated due to their potential association with MC or CRF, and AA in children. Firstly, BMI was included as a covariate, considering its well-documented correlation with MC (Robinson et al., 2015; Stodden et al., 2008), CRF (Ortega et al., 2008), and AA (Donnelly & Lambourne, 2011) in youth. BMI was calculated using the measured weight and height and adjusted by gender and age (Kuczmarski et al., 2002). Secondly, sex was included as a covariate, given its influence on MC (Barnett et al., 2016; Lubans et al., 2010) and CRF development (Britton et al., 2020; Stodden et al., 2014), as well as on AA because of its role in cognitive differences during childhood (Stillman et al., 2020). Finally, when MC was the primary predictor, CRF was included as a covariate, and vice versa, due to their well-established, bidirectional relationship (Cattuzzo et al., 2016; Stodden et al., 2014). Given this interdependence, both variables acted as covariates in the models to isolate their unique contributions to AA. This approach enabled a more precise examination of each variable's influence while controlling for their shared variance.

2.4. DATA ANALYSIS

2.4.1. Data analysis of Study 1

The differences in the skill score, time spent, and total score between the original and cognitive CAMSA were first compared using the Wilcoxon signed rank test. DT interference was then computed (Bustillo-Casero et al., 2019) and represented in boxplots (Oliver et al., 2018).

After determining that not all the adolescents had been similarly affected by DT, the profiles of the DT performance were determined, for which the cognitive score, the skill score, and the time spent in the cognitive CAMSA were included as input variables in a Self-Organizing Map (SOM) analysis. This analysis was computed on the Matlab R2021a Program (Mathworks Inc., Natick, United States) and the SOM Toolbox (Version 2.0 Beta) for Matlab (Vesanto et al., 1999).

The SOM analysis was used to classify the participants and provide profiles of their similarities in terms of the dependent variables in a three-step procedure (Pellicer-Chenoll et al., 2015), including: (i) the construction of the neuron network (i.e., 11 × 6 neurons map), (ii) the initialization, in which the value or weight of each input variable was assigned to each neuron in two different ways (i.e., randomized and linear initialization), and (iii) a training step to modify the values or weights of the neurons initially assigned by two different training algorithms (i.e., sequential and batch (Oliver et al., 2018).

Several factors influence the modification of the neuronal weights in each iteration during the training. An input vector (i.e., a study case or subject) is entered in the network, after which the neurons in the lattice "compete" to win the input vectors by achieving the smallest Euclidean distance between its weight vector and the input vector, so that the weight vector of the winning neuron has the closest values to the cases in the neuron. All the neurons in the lattice then adapt their weight values closer to the input vector values. The magnitude of the adaptation depends on two processes: (a) the learning ratio, which has a high value at the start of the training process, which is gradually reduced as the training proceeds; (b) the neighbor function, which determines the adaptation of the winning neuron and the rest of the neurons. The adaptation magnitude is negatively associated with the distance between the neuron and the winner. This process is repeated until the training process ends (Pellicer-Chenoll et al., 2015).

Since the final analysis depends on the random procedure (e.g., initialization and entry order of the input vector), the above-described process was repeated 100 times to increase the odds of finding the best solution. 1,600 SOM were obtained in this way because two different training methods, four neighborhood functions and two initialization methods were used (i.e., 100 × 2 × 4 × 2). After multiplying the quantization and topographical errors, the map with the minimum error was then chosen (Pellicer-Chenoll et al., 2015).

After the SOM analysis, a k-means method was used to classify the neurons into larger groups, according to the input variables' characteristics. The number of clusters was set to range between 2 and 10 to avoid an excessive number of profiles. The final number of clusters was the one with lowest Davies-Bouldin index, which were used to describe individual profiles according to the input variables.

The clusters were lastly compared for both the input variables included in the SOM and by gender and single-task performance. The Corsi Block test output variables (i.e., total correct trials, Block Span, and Memory Span), Digit Span (i.e., total number of correct sequences and Memory Span), and original CAMSA (i.e., motor skill score, time to complete the test, and total score) tests were compared between the clusters using the Kruskal-Wallis test with the Dunn test for pairwise comparisons. The Chi-Squared test was used to detect significant associations between cluster membership and gender, with the level of significance set to $p = 0.05$.

2.4.2. Data analysis of Study 2

The input variables from the physical, social, and psychological domains were used to profile the participants. Descriptive data on actual and perceived CP, math fluency, and AA were then analyzed according to the identified profiles. First, the effect of clustering on the input variables was checked by the Kruskal–Wallis test, with pairwise comparisons between clusters conducted using the Dunn–Bonferroni correction at a significance level of $p = 0.05$.

Secondly, the Kruskal–Wallis test was applied to determine the cluster effect on both subjective (i.e., AA, perceived mathematical performance and perceived language performance) and objective cognitive variables (i.e., math fluency, Digit Span [i.e., Total Recall Score] and Stroop variables [i.e., Dot Time, Word Time, Color Time, Correct Responses Dot, Correct Responses Word, Correct Responses Color, Dot Time Efficacy, Word Time Efficacy, Dot Responses Efficacy and Word Responses Efficacy]). The Dunn-Bonferroni post-hoc correction was then applied.

Finally, gender was compared within the clusters using the chi-square test at a significance level of $p = 0.05$ to identify any significant associations between cluster membership and gender.

2.4.3. Data analysis of Study 3

All statistical analyses were performed using IBM SPSS Statistics v.26 (IBM Corp., Armonk, NY, USA), and the level of significance was set at $p < .05$. Descriptive statistics (means and standard deviations) were calculated for all study variables and are included in Annex 3 (Table S1). The assumption of normality was tested using the Kolmogorov-Smirnov test and visual inspection of histograms and Q-Q plots, which indicated that the data did not follow a normal distribution. However, the sample size was sufficiently large for parametric tests to be considered robust. Thus, independent samples t-tests were performed to compare boys and girls. Additionally, Cohen's d effect sizes were calculated to assess the magnitude of differences. Therefore, in order to maintain methodological consistency with the linear regression-based mediation models and the t-tests used, Pearson correlation coefficients were computed to assess the strength of associations among variables (i.e., MC, CRF, perceived MC, perceived PF, self-determined motivation for PA, PL self-perception, AA self-perception, and AA). The magnitude of the correlations was interpreted according to well-established criteria, classifying them as slight ($r < .20$), low ($.20 \leq r < .40$), moderate ($.40 \leq r < .70$), high ($.70 \leq r < .80$), and very high ($r \geq .80$). Correlations are shown in Annex 4 (Table S2).

Subsequently, in order to explore the potential mediation effects, multiple (parallel and serial) mediation models were conducted using the PROCESS macro for SPSS (Hayes, 2017). Indirect effects were tested through bias-corrected and accelerated (BCa) bootstrapping procedures with 10,000 resamples, generating 95% confidence intervals (CI). This approach is particularly beneficial for non-large sample sizes, as it provides more accurate estimates of indirect effects and reduces bias in confidence interval estimation (Pan et al., 2018). An indirect effect was considered significant if zero was not included within the confidence interval.

The main multiple serial mediation analysis model was applied with two mediators [X → M1 → M2 → Y (Hayes, 2017)] to test the hypothesized mediation linking MC/CRF to AA through the respective self-perceptions in the physical and academic domain. In a serial model, the mediators are hypothesized to have a directional, ordered relationship. According to Salvatierra-Calderón et al. (2024), we employed a physical-to-cognitive sequence. Specifically, in our three-path model, the independent variable (MC or CRF) was hypothesized to affect the first mediator (physical self-perception), which in turn was expected to influence the second (academic self-perception), ultimately impacting the dependent variable (AA). The model was carried out twice: b1) with MC designated as the predictor variable and b2) with CRF designated as the predictor variable. Sex, age and BMI were added to the model as covariates. Also, when MC was the primary predictor, CRF was included as a covariate, and vice versa. In addition to providing the total and direct effects, this approach offers a detailed examination of multiple indirect effects. Specifically, the model estimates simple two-path mediation links (a_1b_1, a_2b_2), as well the entire three-path mediation link ($a_1d_{21}b_2$), where the mediators are interlinked in a sequential manner. These serial effects reflect the cumulative impact of the ordered mediators on the outcome variable (Hayes, 2017).

A further multiple serial mediation analysis was created by adding PA as the independent variable (four-path mediation: X → M1 → M2 → M3 → Y) to examine the indirect effects of PA on AA through MC or CRF, physical and academic self-perceptions. This model was run four times, entering subjectively reported PA or objectively measured PA as the independent variable, and MC or CRF as the first mediator. Thus, the following serial mediation models were employed: PA (subjective or objective) → physical competence (MC or CRF) → physical self-perception → academic self-perception → AA. The two PA measures were implemented to capture the potential differences in how they relate to MC and CRF.

Before running this serial mediation model, a preliminary analysis was performed to choose the measure of self-perception in the physical domain most appropriate to be entered in the hypothesized mediation chain. To this aim, a multiple parallel mediation analysis was run with MC of CRF as the independent variable, perceived AA as the dependent variable and the four available self-perception variables in the physical domain (perceived MC and PF, perceived autonomous motivation and PL) as parallel mediaton.

RESULTS AND DISCUSSION

3. RESULTS AND DISCUSSION

3.1. RESULTS AND DISCUSSION OF STUDY 1

3.1.1. Results of Study 1

3.1.1.1. Dual-task interference in the cognitive CAMSA

All the descriptive data of the variables used in this study are provided in Annex 1. The results indicate that including cognitive tasks (i.e., decision making) in the cognitive CAMSA significantly reduced the total score while it increased the time spent (Figures 5D,G). Compared to the original CAMSA, the cognitive CAMSA motor skill score therefore did not change significantly (Figures 5A,B). The DT during the cognitive CAMSA thus did not change the students' motor skill score, whereas the time required to perform the test increased. However, when the DT interference is analyzed (Figures 5E,H), it can be seen that not all the participants had better scores in the original CAMSA (Figure 6I) or increased the time spent in the task (Figure 6F). 14% of the subjects had a higher total score in the cognitive CAMSA than in the original version, whereas 73% had lower total scores and the remaining 12% did not change theirs (Figure 6I). Furthermore, 82% of the subjects required a longer time in the cognitive CAMSA than in the original, while 17% reduced the time spent and the remaining 1% did require the same time. Although no significant differences were found between the original and cognitive CAMSA in the motor skill scores, in Figure 6C, it can be seen that 22% of the subjects increased their motor skill scores in the cognitive CAMSA, 22% showed no change, while 56% showed a loss of performance (Figures 6B,C,E,H).

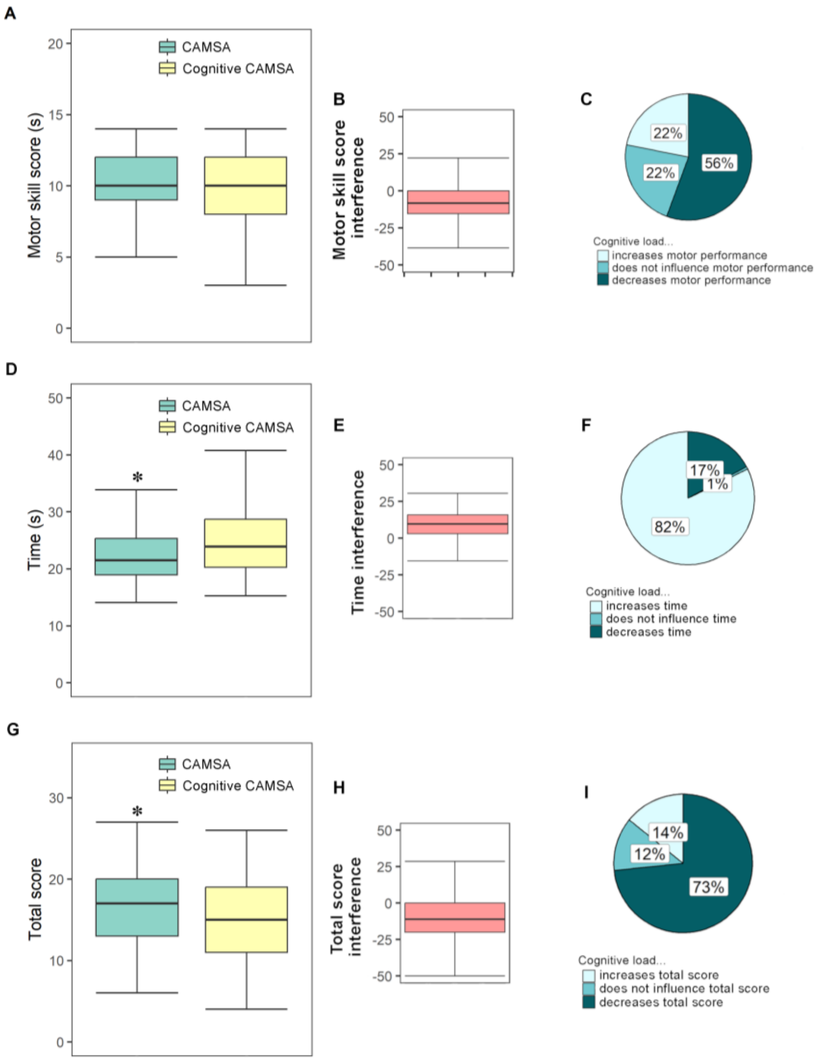

Figure 6. Dual-task interference during the performance of CAMSA test. Layers (A,D,G) show box plots of the values obtained in the motor skill score, time, and total score variables both on cognitive and original CAMSA, respectively. Layers (B,E,H) show box plots of the interference in the motor skill score, time and total score variables when performing dual tasks (i.e., cognitive CAMSA) compared to when performing single tasks (i.e., original CAMSA) respectively. Layers (C,F,I) show the percentage of participants who increase, decrease, or do not change their scores on the variables motor skill score, time, and total score when performing the cognitive CAMSA compared to the original CAMSA, respectively. *indicates significant differences ($p < 0.05$).

3.1.1.2. Performance profiles of cognitive CAMSA

According to the SOM approach and k-means cluster algorithms, using the cognitive CAMSA scores (i.e., cognitive score, skill score, and time spent) as input variables, six performance profiles were obtained (Figure 7). In other words, these six profiles are related to the participants' performance in a DT situation. The association between cluster and gender was not significant ($\chi^2_5 = 10.3$; $p = 0.06$). Even so, clusters 4 and 5 had a higher percentage of males, while clusters 1 and 2 were composed of a higher proportion of girls than boys.

A main effect of cluster membership was found on cognitive score ($H_5 = 146.15$; $p < 0.01$), motor skill score ($H_5 = 102.68$; $p < 0.001$), and time spent ($H_5 = 108.07$; $p < 0.001$). Pairwise comparisons revealed that clusters 3 and 5 reported the highest CP and cluster 2 showed the lowest CP. Clusters 4, 5, and 6 showed higher values than clusters 1, 2, and 3 in the motor skill score, while the time spent for those in cluster 1 was longer than the rest of the participants in other clusters. The individuals in cluster 5 obtained a higher time spent than those in clusters 2, 3, and 4, while those in cluster 2 required a longer time than those in cluster 6.

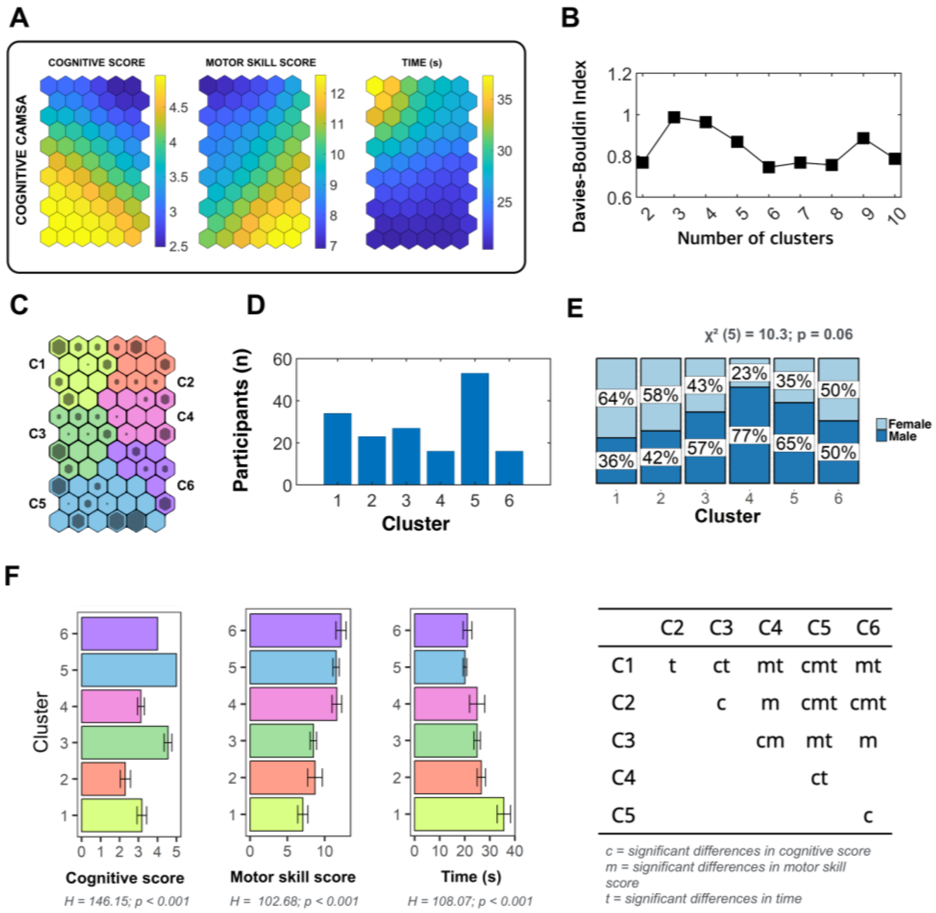

Figure 7. Results derived from Self-Organizing Map analysis in which performance profiles during cognitive CAMSA. Panel (A) shows the component planes resulted from Self-Organizing Maps analysis on cognitive score, motor skill score, and time spent in complete cognitive CAMSA. Panel (B) indicates the Davies-Bouldin index associated with k-means cluster algorithm applied to obtain profiles. Panel (C) shows the six clusters obtained using k-means algorithm with the lowest Davies-Bouldin index. Panel (D) reports the number of participants allocated in each cluster. Panel (E) shows the percentage of girls and boys in each cluster and the chi-square test results. Panel (F) represents the mean and standard deviation of each cluster in each of the variables obtained from cognitive CAMSA as well as Kruskal-Wallis test results. Pairwise comparisons are reported in the table of the layer (F), where each letter (i.e., c, m, and t) indicates in which variable significant differences between clusters were obtained.

3.1.1.3. Differences between clusters in single task performance

The results revealed a significant effect of cluster membership on the motor skill score ($H_5 = 48.46$; $p < 0.001$), time score ($H_5 = 80.28$; $p < 0.001$), and total score ($H_5 = 93.01$; $p < 0.001$) in the original CAMSA test. Pairwise comparisons (Figure 8) showed that clusters 4, 5, and 6 had higher motor skill scores than cluster 1, while cluster 5 had a higher motor skill score than clusters 2 and 3. In the time score, the participants in clusters 5 and 6 were faster than those in clusters 1 and 2, while clusters 3 and 4 were slower than cluster 5. The total original CAMSA score was also lower in cluster 1 than in 4, 5, and 6, while clusters 5 and 6 showed higher values than 2. The values of those in clusters 3 and 4 were lower than those in cluster 5.

In CP, there was a main effect of cluster membership on the total correct trials ($H_5 = 17.15$; $p < 0.004$), block span ($H_5 = 16.47$; $p < 0.006$), and memory span ($H_5 = 15.61$; $p < 0.008$) obtained in the Corsi Block test. Pairwise comparisons (Figure 8) revealed that cluster 5 had higher values in total correct trials, block span and memory span than cluster 1. The rest of the clusters showed no significant differences. In Annex 2, all the pairwise comparisons as well as effect sizes are available.

A main effect of cluster membership was found on the total number of correct sequences ($H_5 = 11.73$; $p = 0.039$) in the Digit Span test, while pairwise comparisons revealed no significant differences between the cluster although accordingly with the r-effect size small-to-medium effects were found between cluster 1 and cluster 4, 5, and 6 in both variables (Annex 2).

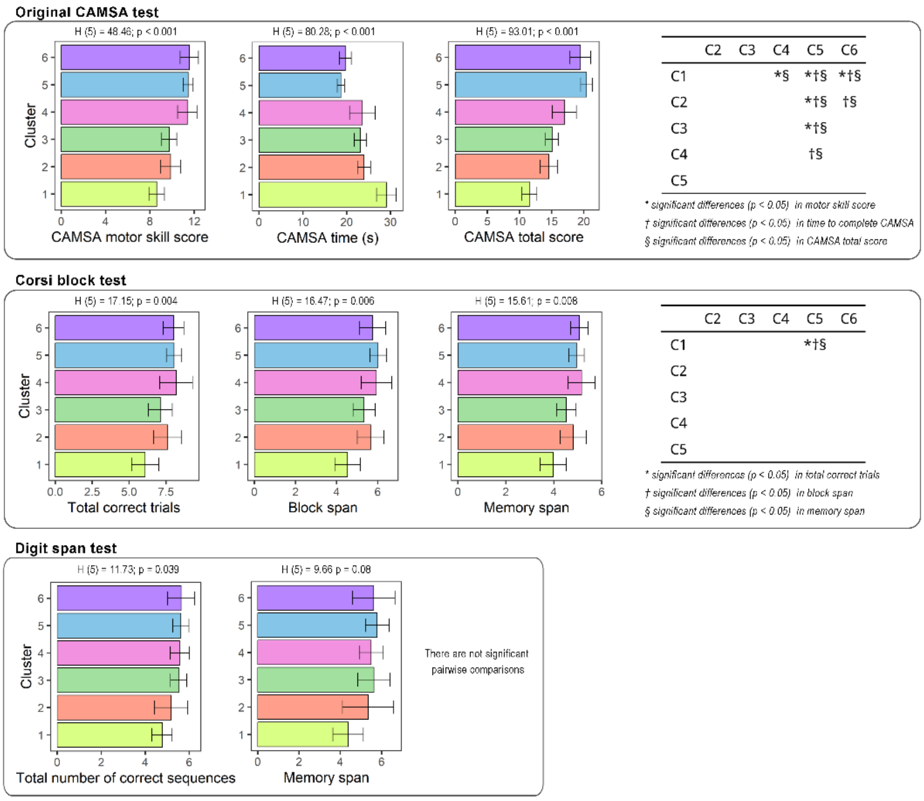

Figure 8. Differences in the variables obtained from original CAMSA, Corsi Block test, and Digit Span test between clusters.

3.1.2.Discussion of Study 1

Including cognitive demands (e.g., decision making) into field-motor tests could provide a new insight into the MC assessment field because, as the setting is maintained, CP can be assessed in an ecological environment just like active games. The purpose of the current study was thus to design and test a cognitive CAMSA, which includes decision making-based verbal and visual cues in order to assess both MC and CP and to analyze the impact of a cognitive load on MC in an ecological setting. In general, and in comparison with the original CAMSA, there were no significant differences in the motor skill score during the application of the cognitive CAMSA. However, the time spent increased, resulting in lower marks in the total score. Interestingly, these results vary widely among the participants in the current study; for instance, some improved their motor skill score (22%), while others did not (22%) or reduced their motor skill score (56%). The same occurred with the time spent, with most the participants increasing the time spent (82%), some reducing it (17%), and a small minority obtaining a similar time (less than 1%). Previous studies have shown an increase in motor performance during DT application, to the detriment of CP (Schaefer et al., 2008). Other studies have shown how DT motor performance can decline, such as Palluel et al. (2010) and Olivier et al. (2010), who found reduced postural control in adolescents and children, respectively, in a DT compared to simple tasks. The effect of a cognitive load added to a motor task on performance still remains unclear, due to the diversity in the results obtained. However, all these previous results have the defect of considering that DT affects everybody in the same way, the present study being the first to analyze DT interference in a person-centered approach.

From our results it can be concluded that a DT does not affect everyone in the same way. The variables analyzed by the cognitive CAMSA included in the SOM gave rise to six profiles, including several profiles that deserve to be highlighted. The cluster 5 scores excel in both cognitive and MC, whether evaluated in isolation or by means of the cognitive CAMSA test, which is considered to be a DT setting. Similarly, cluster 1 shows a lower performance than the rest in both cognitive and MC, whether single or dual tasks. Profiles 1 and 5 include the highest number of participants.

It is interesting to note the existence of a profile (Cluster 2) that shows better CP during seated tests, with a reduced performance in the cognitive CAMSA (i.e., in a DT). In this profile, the individuals exhibited the appropriate levels of MC in both the original and cognitive CAMSA. The cognitive CAMSA could be considered as an adequate stimulus to increase the cognitive effort in this type of profile, given the contrasting performances in cognitive CAMSA (as DT situation) and isolated cognitive tasks. On the other hand, it should be noted that a profile (Cluster 3) emerged that stands out for its CP during the cognitive CAMSA, but not in the simple cognitive tasks. Profile 3 suggests the need to improve motor skills in tasks with a high cognitive load. In terms of CP, there are groups with heterogeneous levels of CP in DT and simple tasks. It should be noted that limited significant differences were found between profiles in seated cognitive test. This can be due to a statistical type II error due to a reduced sample size of each cluster. In Annex 2, some small-to-medium effect size between cluster 1 and clusters 4, 5, and 6 were found in Digit Span test variables. Future works would check if increasing the sample size of the clusters the differences between them emerge as significant.

While some students (profiles 5 and 6) showed good CP in the DT and the simple task, others (profile 2) performed worse in the cognitive tasks during DT than in simple tasks, or vice versa (profile 3). Studies by Howell et al. (2016) and Madehkhaksar and Egges (2016) concluded that the complexity of cognitive tasks can influence motor performance during the execution of a DT. On the one hand, Estevan et al. (34) found reduced performance in motor and cognitive tasks in adolescents as the DT cognitive requirements were increased. On the other hand, Bustillo-Casero et al. (16) detected better adaptation of postural control in DT as the difficulty level of the cognitive task was raised. So far, no single model has been found to explain DT interference, since it affects individuals differently according to unknown factors, which prevents generalizing theoretical models to the whole population. The cognitive CAMSA seems to emerge as a key tool that enables the precise assessment of student DT performance in order to implement the most suitable learning strategies in schools, as it helps us to accurately identify our students' characteristics.

As indicated in the previous paragraph, static and moving cognitive assessment are not clearly equivalent, similar to previous research. In the study by Brilliant et al. (2021), discordance between static and moving cognitive test scores was observed. On the other hand, Ramos-Nuñez et al. (2017), confirmed that different executive functions contribute to task performance depending on task difficulty, with modularity being involved in simple tasks and cognitive flexibility in complex tasks. There have been found profiles that perform isolated cognitive tasks correctly, but not during a DT (Cluster 2) and vice versa (Cluster 3), in line with previous studies (Bustillo-Casero et al., 2019; Howell et al., 2016; Palluel et al., 2010; Schaefer et al., 2008). Trying to measure the PL cognitive domain by means of a DT situation (MC with a cognitive load) instead of a seated cognitive test may be recommended, since it more closely resembles a real sports situation. In this regard, the cognitive CAMSA allows us to assess a CP during motor tasks and at the same time make a global MC assessment (total score) similar to the one performed in the original CAMSA.

Although there were no significant differences in the men/women ratio in the profiles obtained, this aspect requires attention, since the trend toward significance has been found. As can be seen, some profiles have a higher prevalence of males or females that exhibited clearly distinctive characteristics. The frequency of males in clusters 4 and 5, which have medium to high levels of motor skill scores, both in DT and in isolation (i.e., cognitive CAMSA and original CAMSA) is higher than females, while females appeared associated with cluster 1, with lower levels in the afore-mentioned skills. One reason why MC seems to be influenced by gender is that males tend to participate more regularly in PA during the early stages (Abid et al., 2021; Boraita et al., 2020; Kallio et al., 2020). This could be attributed to gender-related social conditioning, which could lead to an erroneous physical self-perception and a negative predisposition to sports participation in girls (Cavallo et al., 2015; Corr et al., 2019; Sabiston et al., 2019) and in turn provide women with fewer opportunities to develop MC. It thus seems essential to equalize the gender participation in sports activities and to improve female students' physical self-perception. These findings highlight the need for educational interventions that equalize the results of boys and girls. It is noted that the context conditions females, as in early childhood boys and girls tend to show similar results in motor skills, which can be even higher in the female gender (Rodríguez-Guerrero et al., 2023). Therefore, implementing programs to encourage girls to take up PA may be key to achieving this goal (Aguilar Jurado et al., 2018). In addition, the professional training of teachers is a factor that can have a strong influence on the development of motor skills in early childhood for both boys and girls (Honrubia Montesinos et al., 2023).

As has been noted, since different factors can influence performance when carrying out a DT, it seems necessary to examine additional factors which in theory are not considered during its assessment. Those with a more developed PL (frequently those with more sports experiences) are likely to obtain higher MC scores (Li et al., 2007; Seidler, 2004; Yang, 2015) and probably also CP during a motor task. Each individual's functional perceived difficulty of a task could also be a conditioning factor (Akizuki & Ohashi, 2015; Aljamal et al., 2019; Goldhammer et al., 2014; Li et al., 2007). It is also possible that different people carry out the same task with more or less effort, and this should be taken into account when evaluating a DT. In addition to enjoyment, it is also important to mention the motivation involved in the task. Those who show greater motivation to perform a DT make a greater effort to improve their performance (Ainley, 2006; Li et al., 2007; Shin & Grant, 2019). In future research, it would be interesting to measure all these factors to obtain results closer to DT evaluation in a more realistic way.

Like most, this study is not without its limitations. Despite the fact that previous studies have shown differences by gender in the levels of MC (Abid et al., 2021; Boraita et al., 2020; Kallio et al., 2020), no significant association between clusters and gender were found in the present study. This divergence can be due to the fact that we are conducting a person-centered approach while previous studies perform the analysis on a variable-centered approach. Secondly, the lack of a specific scoring scale for the cognitive CAMSA (including relative time score) reduced the total score. Future research should consider the application of a separate scale for cognitive CAMSA scoring in this way. Furthermore, it should be noted that in the cognitive tasks of the cognitive CAMSA there is the possibility that a motor error may occur instead of a cognitive error. For example, it is possible that some participants resolved correctly the question about to what target to throw the ball but technically they fail and hit the incorrect target. This has been categorized as a cognitive error but actually it is a motor skill mistake. It should be noted that of the five cognitive decisions to be made, a motor error is only possible in two (throwing and kicking). Moreover, the authors consider that this error is marginal and does not significantly affect the results obtained. Nevertheless, as an alternative, it would be interesting to ask participants to comment aloud on the side of the throw and kick before performing it. Finally, an important area for attention is the need for extensive validity and reliability testing of the Cognitive CAMSA. The lack of extensive validation and reliability testing may limit the consistency and accuracy of the instrument in providing results across different demographic groups and over time. The recognition of this requirement for further validation and reliability testing underlines the need for future research to ensure a full understanding and robustness of the Cognitive CAMSA as an assessment tool.

Regarding the study's practical applications, we can highlight on one hand the design of the cognitive CAMSA, which assessed not only MC, but also CP. The cognitive CAMSA could thus be applied in physical education to assess these two PL aspects in secondary school students and also whether it improves over time. We were also able to determine the profiles of adolescents in performing the cognitive CAMSA and to classify individuals into these profiles to determine their general characteristics and any aspects that should be empowered. For example, a student who performs the cognitive CAMSA and is placed in cluster 5 will be an adolescent with high DT performance (both cognitive and MC) but will also perform well when executing the tasks separately. In view of these results, educational interventions should be considered in physical education based on improving motor and CP in DTs.

In conclusion, a cognitive version of the CAMSA was designed and tested for assessing both motor and CP, which are elements in the physical and cognitive PL domains. We found that the interference generated by the cognitive CAMSA did not affect all the adolescents equally, i.e., we found six student profiles based on their MC and CP. Some of these profiles belonged to adolescents with a similar performance in both DT and single-task contexts (e.g., cluster 5 and 6). However, others showed high MC in single and DT while their CP declined (e.g., cluster 4) or increased (e.g., cluster 3) in DT compared to single tasks. Adolescents will benefit from the cognitive CAMSA because it allows them to be grouped by their performance and any aspects that require to be fostered.

3.2. RESULTS AND DISCUSSION OF STUDY 2

3.2.1. Results of Study 2

This section provides a detailed description of the figures. Figure 9 shows the results of the SOM analysis. To facilitate its interpretation, an explanation is given below. Panels A, B, and C display the component planes for all the input variables, with each section representing one domain. The maps show the distribution of the cases based on their characteristics (yellow [high values], blue [low values]).

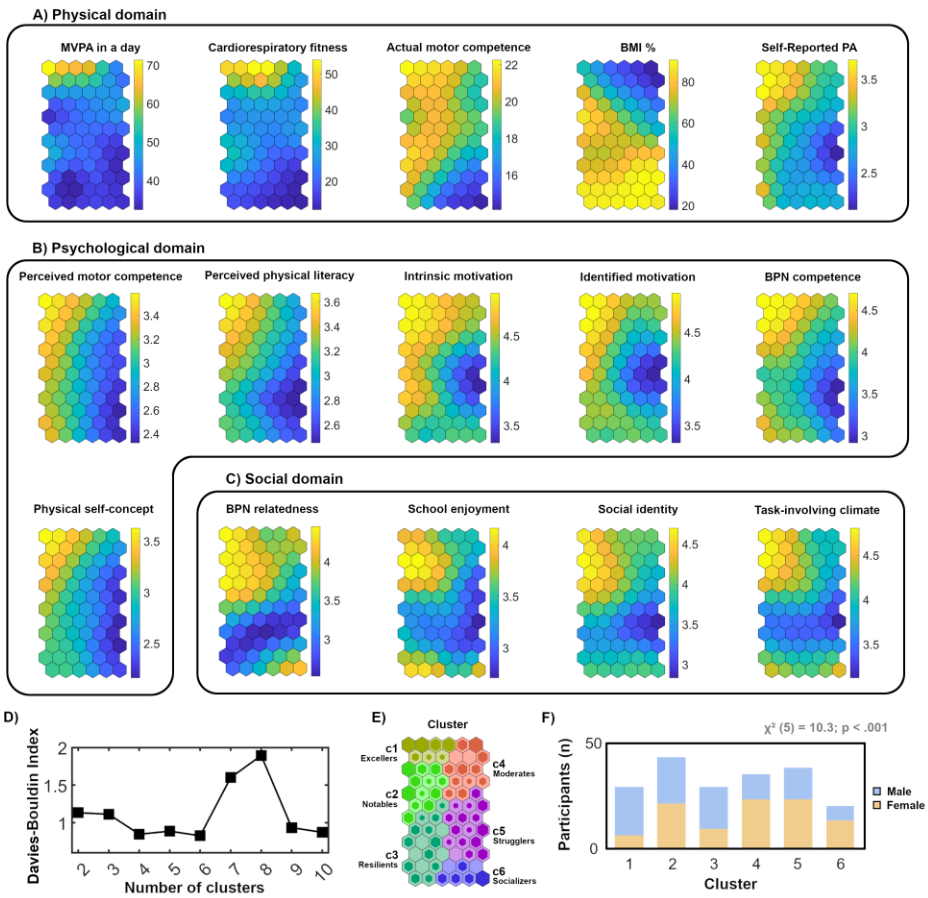

Figure 9. Description of results of Self-Organizing Map analysis. The component planes from the analysis are shown in panels (A), (B) and (C) for the physical, psychological, and social variables of the three domains, respectively. Panel (D) displays the Davies–Bouldin index related to the k-means cluster algorithm applied to set profiles. Panel (E) shows the obtained clusters and the hits (neuron shadows). Panel (F) shows the number of participants in each cluster, the girl/boy percentage in each group and the results of the chi-square test.

The Davies–Bouldin index indicated a 6-cluster solution as the most appropriate (Figure 9D). The neuron distribution in each cluster is shown in Figure 9E. Different colors are assigned to each cluster. The size of the neuron's shadow represents the number of participants classified in each neuron, with larger shadows indicating more subjects.

Each component plane in Figure 9 represents the value of a variable for the participants assigned to each neuron. The participants (cases) remain in the same neuron in all the component planes. For example, the neuron in the lower right corner contains participants who have low scores on variables related to the physical dimension (i.e., daily MVPA, CRF, Actual MC), high BMI percentile, low-to-medium scores on variables related to the psychological domain (i.e., perceived MC, perceived PL, intrinsic motivation, identified motivation, perceived PA participation, basic psychological need of competence, and physical self-concept) and low to moderate scores on the variables in the social domain (i.e., basic psychological need of relatedness, school enjoyment, social identity and task-involving climate). The profiles established are described below.

Cluster 1 (Excellers) comprises participants with high values in all the domains (i.e., physical, psychological, social) and lower BMI percentiles than the rest of the clusters. Cluster 2 (Notables) is formed of children with inconsistent values in the physical domain (i.e., low values in MVPA and fitness, medium actual MC and self-reported PA, and a high BMI percentile). This group obtained a relatively high score in the variables relating to the psychological and social domains, with a solid rating on the variables perceived relatedness in Physical Education and school enjoyment. This cluster contained the largest number of participants. The children allocated to cluster 3 (Resilients) presented low values in the physical domain, except for those obtained in the actual MC variable, which remained relatively high, together with a high BMI percentile. Moderate values were obtained for this group in the psychological and social domains, highlighting high intrinsic motivation and school enjoyment, together with a much lower perceived relatedness in Physical Education than the other clusters. The participants in cluster 4 (Moderates) had medium-to-low scores in the physical domain with a tendency towards a low BMI. The scores were moderate in both the psychological and social domains in relation to those of the remaining clusters. Cluster 5 (Strugglers) showed a physical domain with low tendencies, except for the actual MC variable, in which moderate values were obtained. These participants' BMI percentile was relatively high. The psychological and social domains presented the lowest scores in the sample for all the variables, except for perceived MC, despite having obtained low values for this variable as well. This group had the second-highest number of participants. Finally, the participants in cluster 6 (Socializers) had very low scores in the physical domain and were overweight (90.6 BMI percentile). This group had low-to-moderate scores in the psychological domain, except for intrinsic and identified motivation, which remained high. They also showed high scores in the social domain variables, excluding physical self-concept. This cluster had the smallest number of participants.

The comparison between the clusters (Kruskal-Wallis test) in terms of the SOM input variables showed a significant main effect of cluster membership (Table 4). The clusters' descriptive statistics and pairwise comparisons are shown in Table 5.

Table 4. Cluster effect on input variables

Variables	**χ^2 (5)**	**p**	**ε^2**
MVPA in a day	42.3	< .001	0.22
Cardiorespiratory fitness	82.6	< .001	0.43
Actual motor competence	62.1	< .001	0.32
BMI %	97.5	< .001	0.51
Self-Reported PA	67.8	< .001	0.35
Perceived motor competence	115.0	< .001	0.60
Perceived physical literacy	105.4	< .001	0.55
Intrinsic motivation	95.2	< .001	0.49
Identified motivation	87.4	< .001	0.45
Perceived competence in PE	77.1	< .001	0.40
Physical Self-Concept	107.4	< .001	0.56
Perceived Relatedness in PE	84.0	< .001	0.44
School enjoyment	41.2	< .001	0.21
Social identify	75.3	< .001	0.39
Task involving climate	70.0	< .001	0.36

Table 5. Descriptive statistics of input variables and pairwise comparisons.

Variables	**Cluster 1 Excellers n = 29**	**Cluster 2 Notables n = 43**	**Cluster 3 Resilients n = 29**	**Cluster 4 Moderates n = 35**	**Cluster 5 Strugglers n = 38**	**Cluster 6 Socializers n = 20**
MVPA in a day	70.43* (32)	34.86^{C1} (22.2)	$34^{C1, C4}$ (21.1)	$40.57^{C1, C3, C5}$ (22.3)	$33.57^{C1, C4}$ (21.4)	33.88^{C1} (20.5)
Cardiorespiratory fitness	56* (20)	$26^{C1, C5, C6}$ (15.5)	$22^{C1, C2, C6}$ (15)	$28^{C1, C5, C6}$ (15)	$19^{C1, C2, C4, C6}$ (11.8)	11* (6.5)
Actual motor competence	$22^{C4, C5, C6}$ (4)	$21^{C4, C5, C6}$ (5)	$20^{C5, C6}$ (3)	$19^{C1, C2, C6}$ (3.5)	$19^{C1, C2, C3, C6}$ (4)	14.5* (3.25)
BMI %	$37^{C2, C3, C5, C6}$ (32.4)	$81.5^{C1, C4}$ (22.5)	$79.5^{C1, C4}$ (20.9)	$28.1^{C2, C3, C5, C6}$ (25.7)	$79.35^{C1, C4, C6}$ (27.2)	$90.6^{C1, C4, C5}$ (8.6)
Self-Reported PA	$3.48^{C3, C4, C5, C6}$ (0.49)	$3.42^{C3, C4, C5, C6}$ (0.91)	$2.99^{C1, C2, C5}$ (0.66)	$3.02^{C1, C2, C5}$ (0.57)	2.30* (0.89)	$2.89^{C1, C2, C5}$ (0.51)
Perceived motor competence	$3.55^{C3, C4, C5, C6}$ (0.3)	$3.35^{C4, C5, C6}$ (0.45)	$3.15^{C1, C4, C5, C6}$ (0.4)	$2.7^{C1, C2, C3}$ (0.63)	$2.58^{C1, C2, C3}$ (0.44)	$2.53^{C1, C2, C3}$ (0.63)
Perceived physical literacy	$3.63^{C3, C4, C5, C6}$ (0.23)	$3.43^{C3, C4, C5, C6}$ (0.28)	$3.17^{C1, C2, C5, C6}$ (0.37)	$2.97^{C1, C2, C5}$ (0.33)	$2.6^{C1, C2, C3, C4}$ (0.52)	$2.75^{C1, C2, C3}$ (0.48)
Intrinsic motivation	$5^{C3, C4, C5, C6}$ (0)	$5^{C3, C4, C5, C6}$ (0.33)	$4.67^{C1, C2, C5}$ (0.67)	$4.67^{C1, C2, C5}$ (0.33)	3.67* (1)	$4.33^{C1, C2, C5}$ (0.75)
Identified motivation	$5^{C3, C4, C5, C6}$ (0.33)	$5^{C3, C4, C5, C6}$ (0.67)	$4.33^{C1, C2, C5}$ (0.67)	$4.33^{C1, C2, C5}$ (0.67)	3.67* (0.33)	$4.33^{C1, C2, C5}$ (0.67)

Table 5. Descriptive statistics of input variables and pairwise comparisons (continued).

Variables	Cluster 1 Excellers n = 29	Cluster 2 Notables n = 43	Cluster 3 Resilients n = 29	Cluster 4 Moderates n = 35	Cluster 5 Strugglers n = 38	Cluster 6 Socializers n = 20
BPN competence	$4.8^{C3, C4, C5, C6}$	$4.4^{C4, C5, C6}$	$4.2^{C1, C5}$	$4^{C1, C2, C5}$	3.2*	$3.8^{C1, C2, C5}$
	(0.4)	(1)	(0.6)	(0.8)	(0.8)	(0.65)
Physical Self-Concept	3.5*	3.33*	$3^{C1, C2, C4, C5, C6}$	$2.67^{C1, C2, C3}$	$2.25^{C1, C2, C3, C4}$	$2.67^{C1, C2, C3}$
	(0.5)	(0.5)	(0.33)	(0.5)	(0.63)	(0.54)
BPN relatedness	$4.2^{C3, C5}$	$4.6^{C3, C4, C5}$	$3^{C1, C2, C4, C6}$	$4^{C2, C3, C5}$	$3^{C1, C2, C4, C6}$	$4.1^{C3, C5}$
	(0.8)	(0.8)	(1)	(0.6)	(1)	(1.1)
School enjoyment	3.8^{C5}	$4^{C3, C4, C5}$	$3.6^{C2, C5}$	$3.4^{C2, C5}$	2.8*	3.8^{C5}
	(1)	(0.8)	(1)	(0.9)	(1)	(1.2)
Social identify	4.56^{C5}	$4.56^{C3, C4, C5, C6}$	$3.67^{C1, C2, C5}$	$4^{C2, C5}$	3.22*	$3.89^{C2, C5}$
	(1.22)	(0.72)	(0.89)	(0.72)	(0.64)	(0.61)
Task-involving climate	$4.6^{C3, C4, C5}$	$4.6^{C3, C4, C5}$	$3.6^{C1, C2, C6}$	$4^{C1, C2, C5}$	$3.4^{C1, C2, C4, C6}$	$4.4^{C3, C5}$
	(0.8)	(0.8)	(0.8)	(0.4)	(0.6)	(0.61)

Data are expressed as median (interquartile range). * Indicates significant differences with all clusters. [C1] indicates significant differences with Cluster 1. [C2] indicates significant differences with Cluster 2. [C3] indicates significant differences with Cluster 3. [C4] indicates significant differences with Cluster 4. [C5] indicates significant differences with Cluster 5. [C6] indicates significant differences with Cluster 6.

The comparison of the cognitive domain variables in the different clusters revealed a significant cluster effect on AA ($H_5 = 18.83$; $p < 0.002$). However, no significant effects were observed for the other subjective cognitive variables (i.e., perceived mathematical performance and perceived language performance). Pairwise comparisons (Figure 10) revealed that clusters 1 and 4 had higher AA scores than cluster 5.

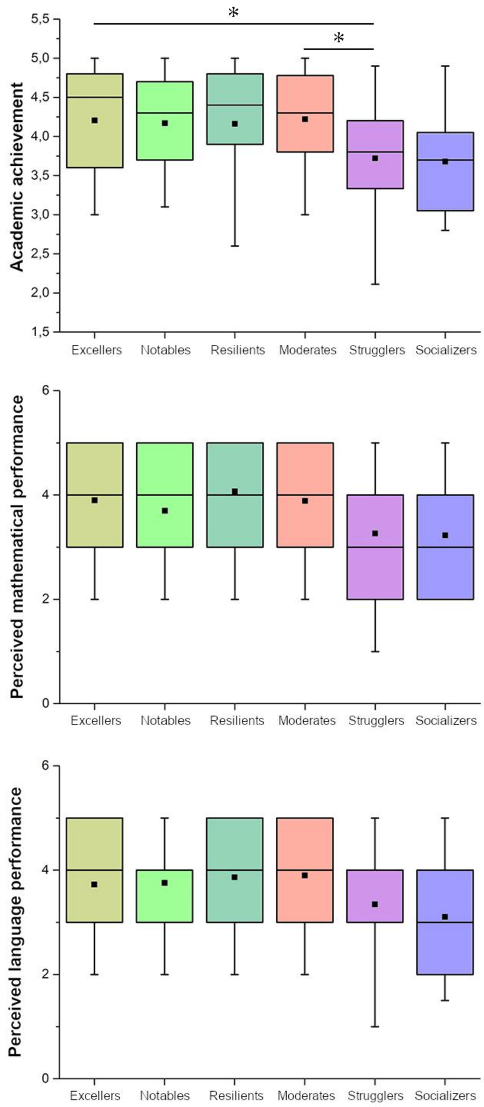

Figure 10. Pairwise comparisons of cognitive domain variables between clusters. The box plots display median values, interquartile ranges, and outliers for each cluster across three variables: AA (left), perceived mathematical performance (center), and perceived language performance (right). Significant differences between clusters are indicated by asterisks (*$p < 0.05$).

Table 6 shows the cluster effect on objective cognitive variables math fluency, Digit Span test and Stroop test variables. The pairwise comparisons are shown in Table 7.

Table 6. Cluster effect on Digit Span test and Stroop test variables.

Variables	χ^2 (5)	p	ε^2
Mathematical fluency			
Correct operations	28.54	< .001	0.1479
Digit Span test			
Total Recall Score	4.43	0.49	0.02293
Stroop test			
Dot Time	8.49	0.131	0.04398
Word Time	17.67	0.003	0.09154
Color Time	13.68	0.018	0.07086
Correct Responses Dot	16.54	0.005	0.08571
Correct Responses Word	4.98	0.418	0.02583
Correct Responses Color	7.69	0.174	0.03983
Dot Time Efficacy	5.6	0.347	0.02904
Word Time Efficacy	1.41	0.923	0.00732
Dot Responses Efficacy	2.86	0.722	0.01481
Word Responses Efficacy	4.12	0.532	0.02136

Dot Time: The average time in seconds taken by the subject to complete the color in the dot task. Word Time: The average time in seconds taken by the subject to complete the color in the neutral word task. Color Time: The average time in seconds taken by the subject to complete the color in the color word task. Total Responses Dot: The average total responses made in the dot task. Total Responses Word: The average total responses made in the neutral word task. Total Responses Color: The average total responses made in the color word task. Dot Time Efficacy: The time used to complete the color word task divided by the time used to complete the dot task. Word Time Efficacy: The time used to complete the color word task divided by the time used to complete the neutral word task. Dot Responses Efficacy: The total responses used to complete the color word task divided by the total responses used to complete the dot task. Word Responses Efficacy: The total responses used to complete the color word task divided by the total responses used to complete the neutral word task.

Table 7. Descriptive statistics of Digit Span test and Stroop test variables and pairwise comparisons.

Variables	**Cluster 1 Excellers**	**Cluster 2 Notables**	**Cluster 3 Resilients**	**Cluster 4 Moderates**	**Cluster 5 Strugglers**	**Cluster 6 Socializers**
Mathematical fluency						
Correct operations	26^{c6}	$29^{c5, c6}$	$28^{c5, c6}$	23	$21^{c2, c3}$	$21.5^{c1, c2, c3}$
	(6)	(8.5)	(7)	(9.5)	(11)	(8)
Digit Span test						
Total Recall Score	5	5	5	5	4	5
	(1)	(1)	(1)	(1)	(1)	(1)
Stroop test						
Dot Time	63.9	64.5	51.6	64.3	64.5	76.1
	(25)	(32.1)	(36.3)	(25.7)	(30.9)	(31.2)
Word Time	51.7	52.1	$41.5^{c4, c6}$	53.5^{c3}	48.5	62.9^{c3}
	(19.8)	(21.1)	(13.5)	(30.3)	(27)	(30.2)
Color Time	64.3	59.5	49.3^{c6}	65.8	58.7	74.4^{c3}
	(19.6)	(28.2)	(26.2)	(31.2)	(33.1)	(42.8)
Total Responses Dot	24^{c2}	25^{c1}	25	25	24	25.5
	(1)	(2)	(3)	(3)	(2)	(1.25)
Total Responses Word	24	25	25	25	25	25
	(1)	(2)	(4)	(2.5)	(2)	(2)

Table 7. Descriptive statistics of Digit Span test and Stroop test variables and pairwise comparisons (continued)

Variables	Cluster 1 Excellers	Cluster 2 Notables	Cluster 3 Resilients	Cluster 4 Moderates	Cluster 5 Strugglers	Cluster 6 Socializers
Total Responses Color	25	25	26	26	25	26.5
	(3)	(3)	(4)	(4)	(3)	(1.25)
Dot Time Efficacy	0.91	0.94	0.83	0.97	0.82	1.06
	(0.72)	(0.3)	(0.34)	(0.5)	(0.43)	(0.46)
Word Time Efficacy	1.16	1.08	1.15	1.1	1.11	1.15
	(0.55)	(0.51)	(0.33)	(0.4)	(0.33)	(0.46)
Dot Responses Efficacy	1.04	1	1	1.04	1	1.04
	(0.16)	(0.1)	(0.09)	(0.12)	(0.12)	(0.1)
Word Responses Efficacy	1	1	1	1	1	1.06
	(0.08)	(0.12)	(0.12)	(0.16)	(0.12)	(0.08)

Dot Time: The average time in seconds taken by the subject to complete the color in the dot task. Word Time: The average time in seconds taken by the subject to complete the color in the neutral word task. Color Time: The average time in seconds taken by the subject to complete the color in the color word task. Total Responses Dot: The average total responses made in the dot task. Total Responses Word: The average total responses made in the neutral word task. Total Responses Color: The average total responses made in the color word task. Dot Time Efficacy: The time used to complete the color word task divided by the time used to complete the dot task. Word Time Efficacy: The time used to complete the color word task divided by the time used to complete the neutral word task. Dot Responses Efficacy: The total responses used to complete the color word task divided by the total responses used to complete the dot task. Word Responses Efficacy: The total responses used to complete the color word task divided by the total responses used to complete the neutral word task. Significant gender differences were detected using the chi-square test ($\chi^2_5 = 21.0$; $p < .001$). Clusters 1 and 3 had a greater number of boys, while clusters 4, 5, and 6 had a greater number of girls. Cluster 2 had a more balanced gender distribution.

3.2.2. Discussion of Study 2

Examining the relationships among the physical, psychological and social domains primarily related to PA and their influence on CP enhances our understanding of human development, providing a basis for interventions aimed at fostering these areas during childhood. This study aimed to examine the combined impact of these factors on children's CP, by analyzing them interactively rather than in isolation, offering a holistic understanding of their interplay. This approach led to the identification of six distinct profiles, each associated with different CP levels. While previous research has often focused on isolated relationships — such as between physical and cognitive (de Bruijn et al., 2019; Esteban-Cornejo et al., 2015; Ruiz-Ariza et al., 2017; Singh et al., 2019), physical and psychological (Li et al., 2024; Reeve & Lee, 2019; Wang et al., 2019), physical and social (Hu et al., 2021; Yosep et al., 2022), cognitive and psychological (De Meester et al., 2020; Zahra et al., 2010), or cognitive and social (Bizumic et al., 2009; O'Malley et al., 2015) — the person-centered approach used here provides a more comprehensive view. This approach reveals nuanced profiles by considering the dynamic interactions among domains, thus enriching our understanding of individual CP development pathways.

This perspective allows for the observation of variable interactions within the generated profiles, avoiding the loss of relevant information in their interaction process. Overall, profiles with high scores across several domains (i.e., Excellers, Notables, Resilients and Moderates) generally exhibit moderate-to-high CP levels. In contrast, profiles with low scores in one or more domains (i.e., Strugglers and Socializers) usually exhibit poor scores in CP outcomes. The initial analysis suggests a consistent interrelationship among the domains, as children with high values in the physical domain often demonstrate similarly high values in the psychological, social and cognitive domains, indicating a strong cross-domain synergy.

The profiles with generally high scores in the physical domain (i.e., Excellers and Moderates) showed elevated AA scores, corroborating previous studies linking high CRF and lower BMI to better cognitive outcomes (Donnelly et al., 2016; He et al., 2019; Marques et al., 2018). Within the physical domain, CRF (Álvarez-Bueno et al., 2020; de Bruijn et al., 2019; Malambo et al., 2022) and MVPA (Esteban-Cornejo et al., 2015; Fedewa & Ahn, 2011; Sember et al., 2020) appear to play particularly critical roles, as these components are often associated with improved CP and AA.

This reinforces the importance of fostering opportunities for regular PA and sporting activities among younger pupils.

Conversely, profiles with moderate scores in the physical domain (i.e., Notables and Resilients) exhibited stronger CP in objective measures, such as math fluency and Stroop test performance, compared to profiles with generally low physical domain scores (i.e., Strugglers and Socializers). In their study, Katagiri et al. (2021) identified the same relation. Compensatory strengths in the psychological and social domains may enhance CP scores, offsetting moderate physical domain scores. Furthermore, the Strugglers and Socializers' profiles obtained the lowest CP scores. Both profiles exhibited low scores not only in the physical domain but also in the psychological domain. Notably, the Strugglers' profile also demonstrated low scores in the social domain. This observation underscores the importance of fostering development across all domains, as each one appears to play a complementary role in supporting cognitive outcomes. Additionally, as these low-CP profiles (i.e., Strugglers and Socializers) include a higher proportion of girls, ensuring equitable opportunities for both genders to engage in diverse forms of PA — aligned with their interests and beyond the traditional and stereotyped sports — becomes essential (Telford et al., 2016). Promoting PA that caters to diverse motivations and preferences can help children maximize their physical and cognitive potential across domains. Encouraging varied forms of physical engagement may help bridge the CP gap, particularly among children who may not naturally gravitate toward conventional PA.

It is crucial to highlight the cluster profiles that have consistently achieved higher results across various domains, as in the case of Excellers and Notables. The Excellers' profile exhibited considerable differences from the Notables, including higher scores in MVPA, CRF, and physical self-concept, as well as lower BMI. Given the similarities in these groups' psychological and social variables, it should be noted that their main distinctions lie within the physical domain. This observation suggests that providing targeted support in the physical domain for children within the Notables profile may help them transition closer to the Excellers profile, which demonstrated more favorable overall scores. Therefore, it may be beneficial to consider strategies that enhance these students' physical self-concept, daily PA, and CRF through Physical Education and extracurricular sports activities. Progress in PA-related areas could positively contribute not only to their CP development (Filgona et al., 2020; Owen et al., 2023; Singh et al., 2019) but also to improved physical self-perception as they mature (De Meester et al., 2020). In this regard, families and the educational community can play pivotal roles (Hu et al., 2021; O'Malley et al., 2015; Yosep et al., 2022) with families promoting active lifestyles at home and schools providing structured opportunities to build fitness, confidence, and a positive physical self-concept, considering children's interests and motivations.

Among profiles with moderate scores across most domains, Resilients and Moderates displayed notable characteristics. The Resilients, predominantly male (69%), proved to be highly competent in objective CP tests, scoring significantly higher than Moderates, Strugglers and Socializers, despite having only moderate scores in the physical, psychological and social domains. In contrast, the Moderates, mostly female (65.7%), obtained the lowest BMI among all profiles and similar scores in psychological and social variables compared to Resilients. Moderates reported lower perceived MC and physical self-concept, but achieved higher scores in basic psychological need of relatedness. These findings suggest that while Moderates show lower perceived competence (Barnett et al., 2016; Estevan et al., 2021), their consistent engagement in PA could be influenced by higher levels of relatedness and social support. The observed differences between these two profiles may partially reflect gender-related disparities in physical development and the influence of socialization on physical competence perceptions (De Meester et al., 2020). Understanding these factors is crucial, as they can shape motivation and participation in PA, particularly as children transition into adolescence. To support the optimal development of students within these profiles, it is essential to implement targeted strategies that promote PA, develop a positive self-concept and enhance perceived MC. School-based interventions that promote diverse PA options (Liu et al., 2015) reduce screen time (Suchert et al., 2016) could address the tendency of these profiles to undervalue their physical abilities, despite often exhibiting strong physical domain development. Such measures can foster these improvements, emphasizing the crucial roles of the educational community and family environment in promoting active, healthy lifestyles.

The Strugglers profile (60.05% girls) consistently scored low across most domains. Despite not being the least proficient physically, these individuals showed the lowest values in both psychological and social domains, resulting in poor CP in both objective and subjective measures. This suggests that the children within this profile may be at risk of atypical development, primarily due to low motivation and limited social support. Although the Strugglers scored higher in actual MC than Socializers, they displayed significantly lower scores in motivational aspects and overall social engagement. This highlights the need for targeted interventions that focus on enhancing motivation and fostering a supportive social environment, as deficits in these areas can negatively influence PA engagement and related psychological outcomes (Niemistö et al., 2023). Tailored Physical Education programs that emphasize building motivation and strengthening social connections could play a crucial role in supporting these students (Filgona et al., 2020; Owen et al., 2023; Singh et al., 2019). Educators should prioritize early identification and provide targeted support to address these challenges effectively and mitigate potential development risks.

The Socializers' profile (65% girls), displayed moderate-to-low scores in physical and psychological domains, as well as in CP, except for strong performance in the social domain, which occasionally exceeded that of Resilients and Strugglers. Despite their social strengths, the Socializers exhibited low levels of PA, actual MC and physical fitness, alongside high BMI and low self-perception. Nevertheless, their CP was the lowest across all profiles. Interestingly, their moderate scores in intrinsic and identified motivation, as well as their positive social self-perception and school enjoyment suggest that social support from family, teachers and peers may play a compensatory role, bolstering their engagement despite weaker physical performance (Harmelen et al., 2017). In light of these findings, strategies that leverage their social skills and motivation for sports could enhance their physical, psychological, and cognitive development. Novel pedagogical strategies in Physical Education could promote extracurricular engagement and improve their overall profile (Sierra-Díaz et al., 2019). Future longitudinal studies are needed to explore whether such strategies could facilitate a shift towards profiles with higher physical, psychological and cognitive attributes.

It is important to point out that this study is not without limitations. As previously stated, it is crucial to consider the importance of examining different domains when creating profiles and their relationships with CP. Additionally, unmeasured variables, such as socio-economic level (Sartika et al., 2021), nutrition (Roberts et al., 2022), and sleep time (Mason et al., 2021), may significantly impact profile development and CP. The analysis relied on a cross-sectional cohort design, and future longitudinal studies are needed to track the changes in the variables over time. While the selected CP tests provided valuable insights, they revealed subtle differences among students within the same grade, suggesting the need for a broader range of tests to capture diverse executive functions. Expanding the assessment could help identify more distinct cognitive strengths and weaknesses across profiles, enabling the development of more targeted educational strategies.

In summary, this study used a person-centered approach with SOM to identify six distinct student profiles, shaped by varying interactions across physical, psychological and social domains. Our findings reveal that profiles with moderate-high scores in physical (i.e., Excellers, Notables, Resilients and Moderates) consistently obtained higher CP scores, as evidenced by superior results in objective cognitive measures (e.g., Stroop test and math fluency). In contrast, profiles with lower scores in physical and psychological domains (i.e., Strugglers and Socializers) exhibited the lowest CP, underscoring the critical role of these domains in cognitive development.

The analysis highlights the complex, non-linear evolution of these domains, revealing unexpected patterns, particularly in the Strugglers and Socializers, who did not conform to typical assumptions linking low physical competence to poor CP. Instead, motivational deficits and weaker social engagement appeared to contribute more significantly to their lower cognitive outcomes. These insights emphasize the need to look beyond PA promotion alone, focusing on enhancing self-perception, motivation, and social support as part of a comprehensive strategy for cognitive development.

Understanding these distinct profiles offers valuable guidance for educators and stakeholders in educational and sporting contexts. Tailored interventions addressing the specific strengths and weaknesses of each profile can reduce inequalities and foster inclusivity. By promoting PA and supporting positive self-concept development, such targeted programs can enhance children's physical, cognitive, psychological, and social well-being. Future research should prioritize longitudinal studies to monitor the evolution of these profiles and implement personalized interventions that align outcomes across all domains, ultimately improving educational and social conditions for all children.

3.3. RESULTS AND DISCUSSION OF STUDY 3

3.3.1. Results of Study 3

3.3.1.1. Preliminary analyses

Results from the preliminary analyses are reported in Annex 3 and 4. That is, descriptive statistics (mean and standard deviation) according to the children's sex, and correlation among the study variables are reported in Annex 3 (Table S1) and Annex 4 (Table S2), respectively. Furthermore, the results of the two multiple parallel mediation models with MC (a1) and CRF (a2) as the predictor variable, academic perception as the final dependent variable and the four self-perception variables in the physical domain as parallel mediators are reported in Annex 5 (Figures S1) and Annex 6 (S2), respectively. Both show that the only significant mediator was perceived PL.

3.3.1.2. Three-path serial mediation analysis: the mediating role of self-perceptions in the association of motor competence and cardiorespiratory fitness with academic achievement

The two multiple serial mediation analyses that were carried out with MC (b1) or CRF (b2) designated as the predictor variable provided similar results. In both instances, perceived PL and perceived AA (utilized as mediators 1 and 2, respectively) were significant mediators of the association between MC (or CRF) and AA.

For model b1) (Figure 11), the mediation between MC and AA resulted in a statistically significant indirect effect through perceived PL and perceived AA (complete serial indirect path: .06; CI = .03 to .11). The total effect of MC on AA was significant (c = .17; p = .029; CI = .02 to .32), but the direct effect was not (c' = .12; $p > .05$; CI = -.02 to .26), indicating full mediation through the proposed pathways. Figure 11 shows that all individual paths composing the three-path mediation were significant. Instead, the direct path from MC to perceived AA and from perceived PL to AA were not statistically significant (*ps* > .05), highlighting the importance of the serial mediation mechanism. The model explained 24% of the variance in AA (R^2 = .24; $p < .001$). Furthermore, the contrast between the indirect effect of the complete serial pathway (MC → perceived PL → perceived AA → AA) and the simple indirect pathway excluding the perceived AA (MC → perceived PL → AA) was statistically significant (-.10; CI = -.18 to -.04), whereas the contrast with the indirect pathway excluding the perceived PL (MC → self-perceived AA → AA) was not.

Model b1)

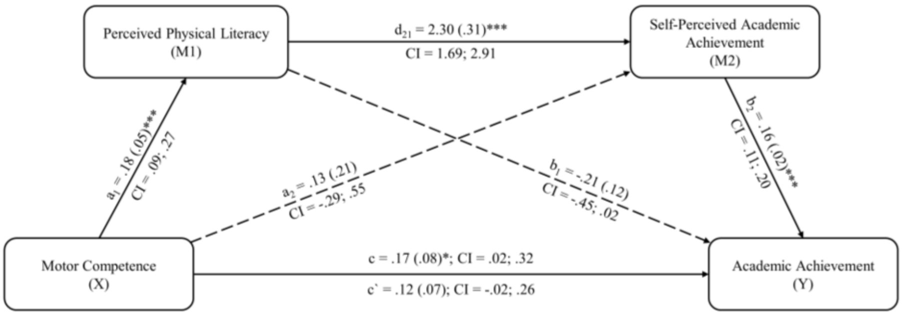

Figure 11. Serial mediation model of the relationship between Motor Competence and Academic Achievement through Perceived Physical Literacy and Self-Perceived Academic Achievement (model b1). Note. n = 218; X: predictor; Y: outcome; M1: mediator 1; M2: mediator 2; CI: confidence intervals; Significant effect — continuous lines; non-significant effect — dashed lines; *p < .05; **p < .005; ***p < .001. The model was adjusted for sex, body mass index and Cardiorespiratory Fitness.

Similar to model b1, also in model b2 the mediation analysis between CRF and AA revealed a statistically significant indirect effect through perceived PL and perceived AA (complete serial indirect path: .003; CI = .001 to .006), even though the effect was less pronounced. In this case, the total effect of CRF on AA was not significant (c = .005; $p > .05$; CI = -.002 to .01), and neither was the direct effect (c' = .006; $p >$ .05; CI = -.001 to .01), indicating inconsistent mediation via the proposed pathway. As shown in Figure 12, all individual paths composing the three-path mediation were significant. Instead, the direct paths from CRF to perceived AA and from perceived PL to AA were not statistically significant (*ps* > .05), emphasizing the importance of the sequential mediation mechanism. Also, this model explained 24% of the variance in AA ($R^2 = .24$; $p < .001$). Additionally, the contrast between the indirect effects of the complete serial pathway (CRF → perceived PL → perceived AA → AA) and the simple indirect pathways excluding one of the two mediators was statistically significant (-.005; CI = -.01 to -.002 and -.005; CI = -.01 to -.001).

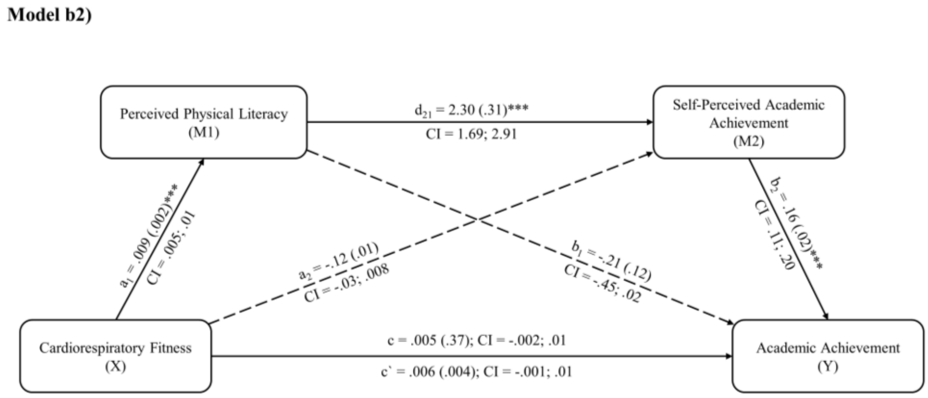

Figure 12. Serial mediation model of the relationship between Cardiorespiratory Fitness and Academic Achievement through Perceived Physical Literacy and Self-Perceived Academic Achievement (model b2). Note. n = 218; X: predictor; Y: outcome; M1: mediator 1; M2: mediator 2; CI: confidence intervals; Significant effect — continuous lines; non-significant effect — dashed lines; *p < .05; **p < .005; ***p < .001. The model was adjusted for sex, body mass index and Motor Competence.

3.3.1.3. Four-path serial mediation analysis: adding physical activity to the model

The two multiple serial mediation analyses that were carried out with self-reported PA as the predictor and MC (c1) or CRF (c2) as the first mediator, and the two corresponding models with objectively assessed MVPA (c3, c4) yielded different results.

In the first two models (c1 and c2), in which self-reported PA served as the predictor, a significant indirect effect of PA on AA emerged (complete serial indirect path: .010; CI = .002 to .021) only when MC was included as the first mediator and CRF as a covariate (model c1: self-reported PA → MC → self-perceived PL → self-perceived AA → AA; Figure 13), not vice versa. The total effect of self-reported PA on AA was non-significant, as was the direct effect (*ps* > .05), suggesting inconsistent mediation through the proposed pathway. As shown in Figure 13, all individual paths composing the four-path mediation were significant. The model explained 24% of the variance in AA ($R^2 = .24$; $p < .001$). Moreover, the contrast between the indirect effects of the complete serial pathway (self-reported PA → MC → self-perceived PL → self-perceived AA → AA) and the simple indirect pathways excluding two of the three mediators were obtained (Contrast with self-reported PA → MC → AA pathway: .018; CI = -.11 to .06, and contrast with self-reported PA → self-perceived PL → AA pathway: -.06; CI = -.14 to .02, and contrast with self-reported PA → self-perceived AA → AA pathway: -.02; CI = -.11 to .06).

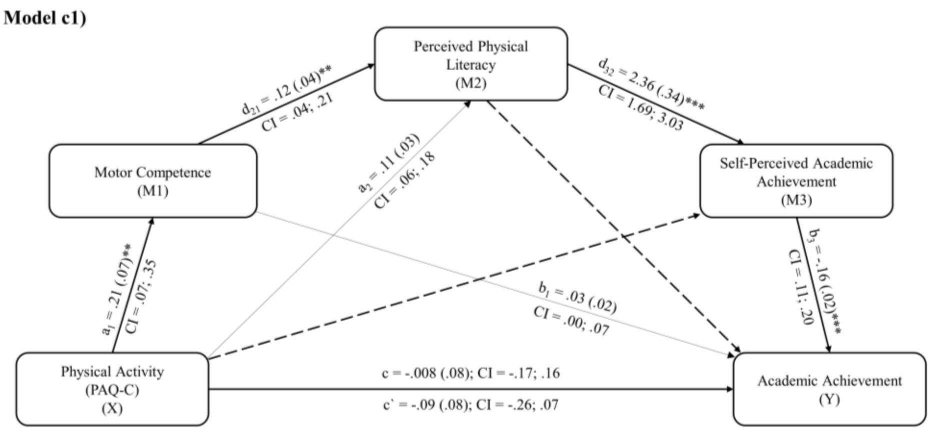

Figure 13. Serial mediation model of the relationship between Self-Reported Physical Activity and Academic Achievement through Motor Competence, Perceived Physical Literacy and Self-Perceived Academic Achievement (model c1). Note. n = 218; X: predictor; Y: outcome; M1: mediator 1; M2: mediator 2; M3: mediator 3; CI: confidence intervals; **p* < .05; ***p* < .005; ****p* < .001. The model was adjusted for sex, body mass index and Cardiorespiratory Fitness.

In contrast, in model c2, in which self-reported PA served as the independent variable and CRF as the first mediator, no significant direct and indirect effects were found. Specifically, neither the complete indirect effect nor any of the indirect pathways was significant, except for the incomplete indirect path linking self-reported PA → PL self-perception → AA self-perception → AA: .11; CI = .06 to .18), indicating that CRF did not mediate the relationship between self-reported PA and AA (see Figure S3, Annex 7).

The reverse pattern of results was found when MVPA was entered as the independent variable (models c3 and c4). A significant indirect effect of MVPA on AA emerged (complete serial indirect path: .0005; CI = .0001 to .001) only when CRF was included as the first mediator and MC as a covariate (model c4: objectively measured MVPA → CRF → self-perceived PL → self-perceived AA → AA; Figure 14), not vice versa.

The total effect of MVPA on AA was not statistically significant, as was the direct effect (*ps* > .05), suggesting an inconsistent mediation through the proposed pathway. As shown in Figure 14, all individual paths composing the four-path mediation were significant. The model accounted for 24% of the variance in AA ($R^2 = .24$; $p < .001$). Likewise, the contrast between the indirect effects of the complete serial pathway (objectively measured MVPA → CRF → self-perceived PL → self-perceived AA → AA) and the simple indirect pathways excluding two of the three mediators were obtained (Contrast with objectively measured MVPA → CRF → AA pathway: .001; CI = -.001 to .003, and contrast with objectively measured MVPA → self-perceived PL → AA pathway: -.0004; CI = -.001 to .0004, and contrast with objectively measured MVPA → self-perceived AA → AA pathway: -.003; CI = -.005 to -.0004).

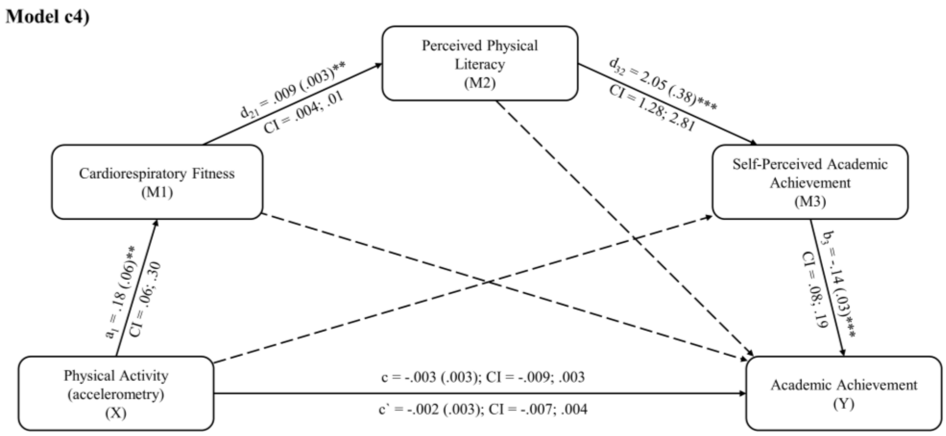

Figure 14. Serial mediation model of the relationship between Moderate to Vigorous Physical Activity and Academic Achievement through Cardiorespiratory Fitness, Perceived Physical Literacy and Self-Perceived Academic Achievement (model c4). Note. n = 148; X: predictor; Y: outcome; M1: mediator 1; M2: mediator 2; M3: mediator 3; CI: confidence intervals; *p < .05; **p < .005; ***p < .001. The model was adjusted for sex, body mass index and Motor Competence.

In contrast, in model c3, in which MVPA served as the independent variable and MC as the first mediator, no significant direct and indirect effects were found. Specifically, neither the complete indirect effect nor any of the indirect pathways was significant, indicating that MC did not mediate the relationship between MVPA and AA (see Figure S4, Annex 8).

3.3.2. Discussion of Study 3

The main purpose of this study was to deepen the understanding of the linkage between children's physical and academic competence by considering psychological mechanisms potentially acting in these associations as psychological self-perceptions in the physical and academic domain. Among the psychological variables that reflected self-perceptions in the physical domain, children's perception of being physically literate – in its broadest, holistic meaning - emerged as a key factor in these relationships. Perceived PL, along with the academic self-perception, bridged the gap between physical attributes and academic outcomes by playing a crucial mediating role. Adopting a serial mediation approach in which self-perceptions were considered (Salvatierra-Calderón et al., 2024), this study sought to provide a more comprehensive understanding of how physical and psychological dimensions interact to influence academic outcomes. The findings highlight the importance of viewing academic success as the result of a holistic interaction between multiple factors, including both physical and psychological ones, emphasizing the critical role of self-perceptions.

The preliminary analyses tested a multiple parallel mediation model (Figures S1-S2, Annex 5 and 6), revealing that among the psychological variables that reflected different perceptions and motivation in the PA and competence domain, the feeling of being physically literate [e.g., Carl et al., (2022)] was the key mechanism linking actual competence in the motor and health-related fitness domains to the perception of being also academically competent. The fact that perceived PL was the only psychological factor to mediate this relationship may be attributed to its multidimensional and holistic nature (Carl et al., 2022), as it integrates physical competence, motivation, confidence, and knowledge about movement, as well as socio-emotional aspect (Cairney et al., 2019; Ortega-Benavent et al., 2024; Whitehead, 2019). The tool chosen to assess perceived PL (Barnett et al., 2022; Ortega-Benavent et al., 2024) is consistent with this comprehensive framework, which bridges cognitive, socio-emotional, and physical domains. Compared to the other, more specific assessments of perceptions selectively focused on motivational, motor skill- or fitness-related perceptions, perceived PL represents the most overarching self-perception in the physical domain, whose multifaceted nature, also including knowledge aspects (Cairney et al., 2019; Whitehead, 2019), likely explains its unique role in linking actual competence and fitness in the physical domain to perceived academic competence. Importantly, identifying a psychological variable that mediates the relationship between MC and CRF and perceived AA suggests that children's overall perceptions in the physical domain influence not only their engagement in movement experiences but also shape and modulate relevant self-perceptions in other achievement domains, such as the academic one, reinforcing the multidimensional nature of self-concept (Marsh & Martin, 2011; Palenzuela-Luis et al., 2022). These findings offer an integrative perspective in the search for mechanisms underlying the relationship between physical and academic performances that goes beyond the traditionally examined cognitive and executive function mediators.

After the identification of PL as the best mediator among the assessed self-perceptions in the physical domain, a multiple serial mediation model was employed to examine the role of self-perceptions in the physical and academic domains for explaining the association between physical performance (MC and CRF, while controlling for their covariation) and academic performance. The results revealed a significant indirect effect of MC on AA through both mediators, with no direct effect remaining once the mediation paths were accounted for (Figure 11). This finding underscores the crucial role of self-perceptions in explaining the association between MC and AA, as children's perception of being physically literate influences how they evaluate their own academic capability. This serial pathway through physical and cognitive-academic perceptions is consistent with Salvatierra-Calderón et al.'s (2024) and makes a step forward under two perspectives. From a methodological perspective, the present study moves beyond a simple, one-item assessment of physical and academic self-perception, especially identifying the multifaceted construct of PL as the best suited to add the missing link. From a conceptual perspective, the present study extends the importance of self-perceptions as probable mechanisms underlying not only the fitness-cognition relation (Salvatierra-Calderón et al., 2024), but also the higher relevance of those mechanisms to explain how the development of competence in the motor skill domain relates to academic performance and success.

In contrast, the mediation model for CRF revealed a weaker indirect effect, with no significant total or direct effect on AA (Figure 12). While CRF was positively associated with perceived PL and perceived AA, its indirect contribution to actual academic performance through these self-perceptions was not as significant pronounced as that of MC, suggesting that its influence may operate through alternative mechanisms, such as cognitive or physiological pathways, which were not captured in the present model (Cadoret et al., 2018; Schmidt et al., 2017; van der Niet et al., 2014). These findings underscore the complementary yet distinct contributions of MC and CRF: MC may exert a more pronounced influence on psychological mediators linked to self-perceptions in the academic domain, while CRF's role potentially reflects a more general impact on brain function and learning processes rather than specific self-perceptual mechanisms involved in AA (Haapala, 2013). This distinction highlights the importance of integrating both physical and psychological dimensions when exploring the pathways through which movement-related competencies influence academic outcomes (Salvatierra-Calderón et al., 2024; Visier-Alfonso et al., 2022).

Building upon these findings, it is relevant to examine PA within the mediation pathways, given the established role of PA as a key contributor to the development of MC and CRF (Lubans et al., 2010; Raghuveer et al., 2020; Stodden et al., 2014). After having identified that physical and academic self-perceptions contribute to identify a way through which actual competence in the physical and academic domains are associated and the first predicts the latter, incorporating PA as a predictor may provide further insight. We explored whether the identified mediation chain may also be useful to explain the still debated association between PA and AA, where effects synthesized in meta-analyses vary from null to moderate (Álvarez-Bueno et al., 2017). Our cross-sectional data showed an inconsistent mediation, in which despite the absence of an overall association, the hypothesized serial mediation was confirmed and showed an indirect effect of PA on AA with a long mediation chain including actual and perceived competence variables.

Intriguingly, the different PA assessments allowed to suggest the existence of different mechanisms though which different aspects of PA may influence its relation with academic success. Our results showed that self-reported PA predicted academic performance only through the mediation chain that included MC (Figure 13), whereas objectively measured MVPA predicted it only through the mediation including CRF (Figure 14). These results suggest that MC and CRF mediate the relationship between PA and AA through distinct mechanisms. These distinct mediation patterns — where self-reported PA was associated with MC but not CRF while MVPA was linked to CRF but not MC — reflect that PA engagement cannot be understood solely in quantitative terms. Rather, self-reported PA captures not only the quantity but also the variety and differentiation of a broader spectrum of activities, including lower-intensity and unstructured movements, influenced by perceived competence and habitual engagement (Marasso et al., 2021). In contrast, MVPA, objectively measured through accelerometry, provides a direct quantification of movement intensity and duration, which aligns more closely with physiological adaptations such as CRF (Aadland et al., 2020). This distinction reinforces the idea that movement quality, perceived competence, and activity diversity shape MC

(Luukkainen et al., 2025), whereas CRF is primarily influenced by structured and moderately to highly intense PA (Franklin et al., 2022).

This study presents strengths, particularly its innovative approach to understanding the role of self-perceptions in linking physical competence (MC and CRF) to academic performance. By integrating self-perceptions in the physical and academic domains as mediators, it expands traditional models that focus solely on cognitive mechanisms, offering a more comprehensive perspective on the interaction between physical and psychological factors and their link to children's academic outcomes. Moreover, by identifying the key role played by a holistic construct of PL — among various measures of perceived competence and motivation in the physical domain — to explain how competence in the physical and academic domains are interrelated, the present study contributes to the growing interest for holistic child development (Stodden et al., 2023). Additionally, the use of both self-reported PA and accelerometer-based MVPA highlights the importance of employing diverse assessment tools, as they could capture distinct aspects of movement behavior (Aadland et al., 2020; Marasso et al., 2021; Skender et al., 2016). These findings have direct practical implications for educational and PA-based interventions, reinforcing the need to foster positive self-perceptions alongside motor and fitness development.

However, certain limitations must be acknowledged. The cross-sectional design prevents establishing causal relationships, underscoring the need for longitudinal studies to explore the long-term impact of these mechanisms. Future longitudinal studies should investigate how PA interventions can effectively enhance both motor and cardiorespiratory competencies, ultimately benefiting cognitive and academic outcomes (Marasso et al., 2021; Skender et al., 2016). Additionally, while the study sample was robust, dropout rates in accelerometer-based assessments may have introduced bias. Moreover, the fact that only models c1 and c4 (linking subjectively reported > PA to MC and MVPA to CRF, respectively) yielded significant indirect effects suggests that the relationship between PA, MC, and CRF may depend on how PA is measured, emphasizing the need for future research to refine these methodological aspects. Furthermore, although the proposed models explained up to 24% of the variance in AA, a substantial portion remains unaccounted for. Future studies should explore additional bioecological factors beyond the individual level — such as family, school, and environmental influences — that may contribute to academic outcomes and interact with physical and psychological variables. These considerations highlight the complexity of AA and the importance of adopting a broader, multifactorial perspective (Bronfenbrenner & Morris, 2007).

In conclusion, the critical role of self-perceptions in mediating the relationship between actual competence in the physical and academic domains is highlighted, reinforcing the need to integrate physical, cognitive, and psycho-social dimensions when examining this connection. The findings demonstrate that MC, and CRF to a lesser extent, exert its influence on AA primarily through holistic self-perceptions of being physically literate and academically competent. From a practical standpoint, interventions should aim not only to enhance physical competencies such as MC and CRF, but also to promote students' confidence and perceived competence in movement-related tasks. Strategies like inclusive physical education programs, structured motor skills development, and constructive feedback mechanisms may prove effective in strengthening self-perceptions and ultimately improving academic outcomes. Additionally, future studies should consider the impact of different PA measurement tools, as subjective and objective assessments capture distinct aspects of movement behavior and may differentially relate to MC and CRF. A multimethod approach will provide a more comprehensive understanding of PA's role in educational contexts.

GENERAL CONCLUSIONS

4. GENERAL CONCLUSIONS

This research project has contributed to expanding current knowledge about the interactions among the domains of PL and its development during childhood. The findings reaffirm the need for continued investigation of this multidimensional construct, its constituent elements, and the dynamic relationships that evolve over time. Specifically, the studies presented in this thesis deepen our understanding of the connection between the physical and cognitive domains, as well as the broader relationship between PL, CP, and AA.

The results highlight several key aspects. First, cognitive demands embedded in motor tasks were shown to significantly influence motor performance, an essential consideration for future research on MC in children. Second, individual differences and the personal development of PL emerged as relevant factors when fostering children's cognitive functions, underscoring the importance of tailored approaches in educational contexts. Finally, the findings demonstrate that psychological aspects (i.e., PL and academic perceptions) play a mediating role in the relationship between physical abilities (i.e., MC and CRF) and AA. This contributes to a more nuanced understanding of how these domains interact and opens new pathways for the design of interventions that support both physical and academic development.

The specific conclusions derived from each study are detailed below.

Study 1

The first study led to the development and validation of a cognitive version of the CAMSA, which enables the simultaneous assessment of MC and CP under DT conditions. The cognitive CAMSA proved to be a feasible and ecologically valid field-based tool for capturing motor performance under cognitive load. Using a SOM approach, distinct performance profiles were identified, reflecting individual differences in how cognitive demands affect motor and cognitive outcomes. While some students maintained similar performance across single and dual tasks, others exhibited marked variations, particularly in CP. These findings support the potential of the cognitive CAMSA as a diagnostic and pedagogical instrument for tailoring interventions based on students' DT profiles in educational and sport settings.

Study 2

The second study employed a person-centered approach to identify PL profiles based on the interplay among physical, psychological, and social domains. These profiles revealed significant effects in daily PA, self-perceptions, and physical performance. Students with higher PA levels and more positive psychological and social characteristics demonstrated better CP, in contrast to those with lower values in these domains. These results emphasize the multidimensional nature of cognitive development and underscore the importance of addressing students' diverse profiles when designing educational strategies. Tailored programs that build upon individual strengths while addressing specific needs may enhance physical, cognitive, and psychosocial outcomes within school settings.

Study 3

The third study demonstrated that the associations between MC and CRF with AA were primarily explained through serial mediation pathways involving perceptions. While the association between PA (both self-reported and objectively assessed) and AA was not significant, an indirect association through serial mediations including physical performance (either MC or CRF), perceived PL and perceived AA emerged.

Distinct serial mediation paths uniquely linked self-reported PA to MC and objectively assessed PA to CRF, followed by final paths linking them to psychological self-perceptions and, lastly, to AA. These findings highlight the relevance of psychological self-perceptions as key mediators and support a holistic view of child development in which PL functions as a central psychological mechanism connecting physical and academic domains. A multimethod approach to assessing PA is recommended to capture these complex interactions more accurately.

LIMITATIONS, PROSPECTIVE AND EDUCATIONAL IMPLICATIONS

5. LIMITATIONS, PROSPECTIVE AND EDUCATIONAL IMPLICATIONS

Limitations

This thesis is not exempt from certain limitations that must be acknowledged when interpreting its findings. The cross-sectional design of the three studies imposes certain constraints. On the one hand, cross-sectional designs rely on data collected at a single point in time, which restricts the ability to capture intraindividual variability or developmental changes across the school year. Important fluctuations in children's performance may therefore have remained unnoticed, and complementary perspectives from families were not included, which could have enriched the interpretation of the results. On the other hand, while the mediation models tested were consistent with the hypothesized direction of effects —with MC and CRF statistically predicting AA through psychological perceptions— the design itself does not allow for definitive causal conclusions. All variables were measured at a single point in time, which limits the ability to confirm temporal ordering and leaves open the possibility that alternative explanations or bidirectional relationships may also exist.

A second limitation concerns the measurement instruments. Although most of them showed appropriate psychometric properties, several relied on self-reports, which may have introduced biases related to subjective perception or social desirability. Moreover, although objective assessments of MC and CRF reduce subjective bias, they may still be influenced by factors such as children's daily motivation or levels of fatigue. In the case of the cognitive CAMSA developed in Study 1, the potential overlap between motor and cognitive errors, may have affected the accuracy of the results. Furthermore, the lack of extensive validation and reliability testing across different populations and age groups limits the generalizability of this tool.

Third, sample-related aspects must be acknowledged. Although the overall sample size was adequate, participants were drawn mainly from public schools in a specific geographical region, which restricts cultural and socioeconomic diversity. Gender differences were not analyzed in depth, and developmental aspects such as biological maturation were not accounted for, despite their potential influence on MC and physical fitness. Additionally, dropout rates in accelerometer-based assessments in Study 3 may have introduced bias, and missing data could have affected the robustness of some findings.

Fourth, certain methodological choices pose limitations. The use of cluster and profile analyses in Studies 1 and 2 offered valuable insights into individual differences, yet the number and type of cognitive tests included may not have been sufficient to capture the full range of executive functions. This may have restricted the detection of more nuanced cognitive strengths and weaknesses within profiles. Similarly, in Study 3, only some mediation models yielded significant indirect effects, suggesting that the relationship between PA, MC, and CRF may be contingent on the type of measurement used. This highlights the need for further methodological refinement when integrating subjective and objective measures.

Finally, while the mediation models applied in Study 3 provided innovative insights into the psychological mechanisms linking physical and academic domains, their complexity bears the risk of overlooking other relevant intervening variables. Even though the models explained up to a quarter of the variance in AA, a substantial proportion remains unaccounted for. Broader bioecological factors — such as family environment, school climate, and community resources — were not considered, yet may substantially interact with physical and psychological variables in shaping academic outcomes. Replicating these findings in different contexts and with more comprehensive models is therefore essential to confirm their robustness.

Prospective

The limitations acknowledged in this thesis open several important avenues for future research. A first priority concerns the need for longitudinal and intervention-based designs. Such approaches would enable researchers to move beyond cross-sectional associations and to examine how PL profiles and their constituent domains develop over time. Longitudinal designs can capture intraindividual trajectories, shedding light on the temporal ordering of effects and the potential bidirectionality between physical and academic outcomes. Intervention studies, in turn, would allow testing the effectiveness of programs specifically designed to strengthen MC, CRF, and self-perceptions, thereby generating stronger evidence for causality.

A second line of prospective work relates to the diversity of samples and contexts. The findings of this thesis were derived from participants in a relatively homogeneous educational environment, and replication in schools with different organizational structures, cultural backgrounds, and socioeconomic conditions is essential to increase external validity. Including children from varied geographical regions and educational systems would provide a more comprehensive understanding of how contextual characteristics interact with motor, psychological, and academic variables.

Future studies should also integrate a broader range of contextual and ecological variables, such as family dynamics, parental support, nutrition, sleep, extracurricular activity participation, and school climate. These factors are likely to play a pivotal role in shaping both motor and academic development and may interact with the mechanisms identified in this thesis. Incorporating these dimensions would contribute to a more nuanced and bioecological understanding of child development.

From a methodological standpoint, there is a clear need to advance the assessment of PL. Expanding the validation of innovative tools, particularly those capable of simultaneously capturing motor and cognitive demands, remains a priority. Their application across different developmental stages and educational levels will be key to consolidating their ecological validity and practical utility. Moreover, the inclusion of a wider battery of cognitive tasks could help capture specific executive functions and offer a more fine-grained analysis of how they relate to motor and psychosocial factors.

Finally, future research should emphasize the design of experimental and school-based interventions that not only aim to enhance physical competence but also intentionally address motivational and self-perceptive mechanisms. Such interventions may contribute to a deeper understanding of the mediating role of psychological factors, while also providing actionable strategies for educators. Mixed-method approaches, combining objective measures with subjective reports and qualitative insights from teachers and families, would further enrich the evidence base, ensuring that the scientific findings translate effectively into educational practice.

Educational implications

From an educational standpoint, the three studies converge on a common message: PL represents a valuable framework for promoting not only physical development but also motivation, confidence, and AA. This reinforces the notion that Physical

Education and school-based movement experiences should be regarded as strategic spaces for fostering holistic learning, in which physical, cognitive, psychological, and social growth are interconnected.

The first study highlights the importance of having innovative assessment tools that allow educators to observe how children respond to complex demands that combine motor and cognitive challenges. Such instruments can serve a dual role: as diagnostic resources to identify students who may require additional support, and as pedagogical tools to inform personalized instruction. By revealing individual differences in DT performance, teachers can design targeted strategies that address both motor and cognitive needs simultaneously, fostering more adaptive learning processes.

The second study emphasizes that academic success is shaped by multidimensional factors, extending beyond physical condition to include psychological and social dimensions. This suggests the need for inclusive educational practices that simultaneously strengthen motivation, social support, and identity, while nurturing MC. Schools should adopt approaches that recognize students' diverse profiles and build upon individual strengths, while also addressing specific needs. Such strategies can contribute to reducing educational inequalities, ensuring that all students have access to environments that support balanced and sustainable trajectories of growth.

The third study demonstrates that self-perceptions of competence and academic ability act as central mechanisms linking physical competence to academic outcomes. This underscores the importance of designing educational programs that do not merely focus on enhancing physical capacities, but also intentionally cultivate confidence, motivation, and a sense of achievement in students. Instructional strategies that emphasize positive feedback, varied opportunities for movement, and structured experiences of success can enhance perceived PL and, ultimately, support academic progress.

Beyond the specific contributions of each study, several broader implications emerge. First, the findings call for teacher training and professional development that equips educators with the knowledge and skills to integrate PL into daily practice, and to recognize its impact on academic as well as physical outcomes. Second, the evidence supports the integration of PL into curricular frameworks, highlighting the potential of interdisciplinary programs that connect Physical Education with other academic subjects. Third, the results suggest the value of early interventions: by addressing motor, psychological, and social domains during childhood, schools can establish a foundation for both lifelong PA and academic success. Finally, the multidimensional approach adopted in this thesis aligns with broader goals of equity and inclusion, encouraging educational systems to design programs that are sensitive to individual differences and contextual factors, and that promote the comprehensive development of all learners.

Taken together, these implications highlight the need to rethink Physical Education as a cornerstone of educational practice, with the potential to contribute decisively to children's physical, cognitive, and academic development. By situating PL at the center of school-based strategies, education systems can better address the complex interplay of factors that shape learning, wellbeing, and lifelong participation in PA.

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6. REFERENCES

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RESUMEN

A continuación, se ofrece un resumen amplio de la tesis doctoral redactado en lengua castellana.

RESUMEN

1. INTRODUCCIÓN GENERAL

1.1. El concepto de Alfabetización Motriz

En las últimas décadas, la investigación en el ámbito de la educación, la salud pública y las ciencias del movimiento ha experimentado un notable interés por comprender de qué manera el desarrollo motor infantil se vincula con otras esferas del desarrollo humano, como el bienestar psicológico, el funcionamiento cognitivo y el rendimiento académico (RA). En este contexto, el concepto de Alfabetización Motriz (AM) ha emergido como un marco integrador que permite repensar el papel de la Educación Física y la AF en el desarrollo global del alumnado, aportando una mirada holística y centrada en la persona.

La AM no se limita a la adquisición de habilidades motrices ni a la mejora del rendimiento físico. Más bien, constituye una competencia compleja y multidimensional que articula aspectos físicos, psicológicos, sociales y cognitivos, posibilitando una participación significativa y sostenida en experiencias motrices diversas a lo largo del ciclo vital. Este constructo se presenta, por tanto, como un puente entre el movimiento y el aprendizaje, entre el cuerpo y la mente, y entre el bienestar individual y la cohesión social.

Numerosos autores han señalado que un adecuado nivel de AM durante la infancia no solo favorece trayectorias vitales más activas y saludables, sino que también puede influir positivamente en la motivación, la autoconfianza, la autorregulación y, en última instancia, en el RA. Desde esta perspectiva, cobra especial relevancia analizar de qué modo los distintos dominios de la AM interactúan entre sí y con otros factores del entorno escolar, para comprender cómo influyen en el rendimiento cognitivo (RC) y académico del alumnado. La presente tesis doctoral se sitúa precisamente en esta intersección, con el objetivo de aportar evidencia empírica que permita esclarecer las relaciones entre la competencia física [i.e., competencia motriz (CM) y aptitud cardiorrespiratoria (ACR)] y el RC y RA, considerando tanto el papel de factores contextuales (como las demandas cognitivas de la AF o los perfiles multidimensionales) como el de mecanismos psicológicos (como la motivación o la percepción de competencia).

1.2. Las dimensiones de la Alfabetización Motriz

El concepto de AM se ha consolidado como una propuesta que trasciende los enfoques tradicionales centrados exclusivamente en el rendimiento físico. Inicialmente formulado por Margaret Whitehead desde una perspectiva filosófica, este constructo fue concebido como una capacidad inherente al ser humano para experimentar el mundo a través del movimiento. A lo largo del tiempo, su definición ha sido ampliada por distintas instituciones y autores, quienes han coincidido en destacar su carácter holístico e integrador. Así, la AM engloba la motivación, la confianza, la competencia física, el conocimiento y la comprensión necesarios para implicarse de forma activa, crítica y reflexiva en contextos motrices variados.

Desde el ámbito de habla hispana, se ha optado por traducir "Physical Literacy" como Alfabetización Motriz, y no "Alfabetización Física", con el fin de enfatizar su enfoque integral y respetar la naturaleza interrelacionada de los dominios que la componen. Esta elección semántica responde al propósito de adaptar el constructo a los marcos educativos y culturales propios del contexto iberoamericano.

El modelo australiano de la AM, ampliamente difundido y adoptado en distintas investigaciones internacionales, propone una estructura basada en cuatro dominios interdependientes: el físico, el psicológico, el social y el cognitivo. Estos dominios no actúan de forma aislada, sino que se influyen mutuamente, dando lugar a trayectorias de desarrollo personal únicas. Esta interrelación es especialmente importante en el ámbito educativo, donde el movimiento no puede abordarse solo desde una perspectiva técnica, sino que debe comprenderse como una experiencia corporal, emocional, social e intelectual.

El dominio físico abarca la destreza en habilidades motrices, la condición física y la capacidad para desenvolverse con eficacia y adaptabilidad en diversos contextos. Es la base funcional del movimiento, pero su desarrollo depende en buena medida de factores motivacionales y emocionales.

El dominio psicológico se refiere a variables internas como la motivación intrínseca, la percepción de competencia, la autoconfianza, la regulación emocional o el placer por moverse. Este dominio es clave para garantizar una participación continuada y significativa en la AF, y actúa como nexo entre la capacidad física y la disposición para implicarse en el aprendizaje.

El dominio social alude a la capacidad para interactuar de forma respetuosa, cooperativa y empática en contextos motrices. Incluye habilidades como la comunicación, la resolución de conflictos, el liderazgo o la inclusión. Su desarrollo refuerza la cohesión grupal, el sentido de pertenencia y la continuidad de la práctica física.

El dominio cognitivo, por su parte, se centra en los procesos mentales implicados en la comprensión, la toma de decisiones y la autorregulación durante la actividad motriz. Se relaciona estrechamente con las funciones ejecutivas (i.e., memoria de trabajo, control inhibitorio y flexibilidad cognitiva), que son fundamentales para el aprendizaje académico.

La combinación y la interacción entre estos dominios permiten entender la AM como una competencia compleja que no puede reducirse a una dimensión única. De hecho, cada persona desarrolla su AM de forma distinta, dependiendo de sus características individuales, su entorno social y las oportunidades educativas que recibe. Esta visión ofrece una base sólida para diseñar intervenciones pedagógicas más inclusivas, personalizadas y sensibles a la diversidad del alumnado.

1.3. La Alfabetización Motriz y su impacto en el desarrollo infantil

El enfoque holístico de la AM ha permitido reconocer su papel no solo en el desarrollo motor, sino también en el bienestar psicológico, la salud física y la competencia social. En la infancia, estos beneficios se articulan en un modelo de retroalimentación positiva: cuando los niños y niñas desarrollan su CM y se sienten motivados y competentes para participar en experiencias motrices significativas, aumentan sus niveles de AF, mejoran su condición física y refuerzan su autoestima y su disposición hacia el aprendizaje.

A nivel fisiológico, se ha comprobado que la práctica de AF y el desarrollo de la ACR están asociados con mejoras estructurales y funcionales en el cerebro, especialmente en regiones vinculadas a la memoria, la atención y la función ejecutiva. A nivel psicológico, la percepción de CM y la motivación autónoma se han relacionado con un mayor bienestar, una mejor regulación emocional y una mayor persistencia ante las dificultades. A nivel social, la participación activa en contextos cooperativos favorece la construcción de relaciones significativas, el aprendizaje de normas y el desarrollo de habilidades prosociales.

Asimismo, la literatura reciente ha destacado que las intervenciones escolares centradas en la AM generan efectos positivos en todos sus dominios. Desde una perspectiva educativa, esto supone una oportunidad para repensar el currículo de Educación Física y para integrar el movimiento en otras áreas del conocimiento, promoviendo una educación más integral y conectada con las necesidades reales del alumnado.

Sin embargo, también persisten ciertos desafíos. La multiplicidad de definiciones, la diversidad de enfoques metodológicos y la falta de consenso en los instrumentos de evaluación han dificultado la comparabilidad entre estudios y la consolidación de una base empírica robusta. Especialmente crítica es la escasa evaluación del dominio cognitivo en situaciones reales, lo que limita el análisis de su interacción con los aspectos físicos.

1.4. Alfabetización Motriz y rendimiento académico

El RA y el RC en la infancia están determinados por una multiplicidad de factores que interactúan entre sí. Estos incluyen variables físicas (e.g., condición física, coordinación), psicológicas (e.g., motivación, autoconcepto), sociales (e.g., apoyo de iguales y docentes) y contextuales (e.g., nivel socioeconómico, estilo de vida, clima escolar). Buena parte de estas variables están incluidas de forma explícita en los distintos dominios de la AM, lo que sugiere que este constructo puede ofrecer una vía explicativa integradora del desempeño académico.

Diversas revisiones sistemáticas han mostrado asociaciones positivas entre la CM y el RA, especialmente en áreas como las matemáticas y la lectura. Asimismo, se ha constatado que niveles elevados de ACR se vinculan con una mayor capacidad de atención, mejores funciones ejecutivas y mejores resultados académicos. No obstante, estos vínculos no siempre son lineales ni homogéneos, y parecen estar modulados por factores individuales como la motivación, la autopercepción de competencia o el tipo de tarea cognitiva implicada.

En este sentido, resulta especialmente relevante adoptar enfoques analíticos que permitan captar la complejidad de estas interacciones. Frente a los tradicionales enfoques centrados en la variable, que analizan relaciones estadísticas aisladas, el enfoque centrado en la persona ofrece la posibilidad de identificar perfiles multidimensionales de alumnado que combinan distintos niveles de desarrollo en los dominios de la AM. Estos perfiles pueden estar asociados con trayectorias distintas de aprendizaje, lo que tiene implicaciones importantes para la intervención educativa.

Del mismo modo, la exploración de los posibles mecanismos que subyacen a esta conexión puede aportar una comprensión más profunda de cómo se relacionan las capacidades físicas con el RA. En particular, se ha propuesto que variables como la motivación autónoma, la percepción de competencia o el autoconcepto académico pueden actuar como puentes psicológicos entre el cuerpo y el aprendizaje, dando sentido a la experiencia escolar desde una perspectiva encarnada e integrada.

2. RENDIMIENTO COGNITIVO Y RENDIMIENTO ACADÉMICO

El RC y el RA constituyen dos dimensiones clave en el desarrollo infantil, íntimamente relacionadas entre sí pero conceptualmente diferenciadas. Mientras el RC hace referencia a la capacidad del individuo para procesar, integrar y aplicar información en contextos diversos, el rendimiento académico se entiende como el grado en que el alumnado alcanza los objetivos curriculares establecidos, en función de los aprendizajes adquiridos a lo largo de su trayectoria escolar.

Durante la infancia, el desarrollo cognitivo sigue un patrón de maduración progresiva que está determinado tanto por factores biológicos como por experiencias ambientales. Entre los procesos mentales que conforman la cognición, las llamadas funciones ejecutivas han recibido especial atención en la literatura reciente. Estas funciones incluyen la memoria de trabajo, el control inhibitorio y la flexibilidad cognitiva, y son consideradas esenciales para la autorregulación, la resolución de problemas, la planificación y el aprendizaje autónomo. Su desarrollo está vinculado a la maduración del córtex prefrontal y se ve especialmente influenciado por la estimulación recibida en contextos educativos y familiares.

Numerosos estudios han demostrado que estas funciones ejecutivas constituyen predictores significativos del RA en áreas como las matemáticas, la lectura o la comprensión verbal, incluso más allá del cociente intelectual o del conocimiento previo. Así, se ha planteado que el éxito escolar no depende únicamente de la adquisición de contenidos, sino también de la eficacia de los mecanismos de regulación cognitiva que permiten gestionar la atención, retener información relevante, inhibir distracciones y adaptarse a nuevas exigencias del entorno escolar.

En cuanto a la evaluación, el RC puede valorarse a través de pruebas estandarizadas como escalas de inteligencia (e.g., WISC) o test específicos de funciones ejecutivas (e.g., Stroop, Corsi, Digit Span). El RA, por su parte, suele medirse mediante calificaciones escolares, valoraciones del profesorado o pruebas normalizadas de rendimiento. Aunque ambos constructos comparten ciertos correlatos, también poseen características y trayectorias distintas, y su evaluación requiere herramientas diferenciadas y complementarias.

Cabe destacar que tanto el RC como el RA están modulados por una amplia variedad de factores físicos, psicológicos, sociales y contextuales. Desde el plano físico, se ha evidenciado que la práctica regular de AF, el desarrollo de la CM y una buena condición física se asocian con mejoras en la atención, la memoria y la autorregulación. Desde el ámbito psicológico, variables como la motivación intrínseca, la percepción de competencia o el bienestar emocional han demostrado incidir positivamente en el compromiso escolar y la persistencia ante la dificultad. A nivel social, el apoyo de la familia, los docentes y los iguales, así como el clima del aula, actúan como moduladores relevantes del desempeño escolar. Finalmente, variables estructurales como el nivel socioeconómico, el capital cultural del hogar o los hábitos de vida (sueño, alimentación, tiempo de pantalla) también influyen de manera significativa en las oportunidades de aprendizaje.

Estos hallazgos ponen de manifiesto que el RA no puede comprenderse únicamente desde una óptica instruccional o curricular, sino que debe analizarse en relación con los procesos cognitivos subyacentes y los múltiples factores que los condicionan. En este sentido, resulta pertinente incorporar marcos explicativos que permitan integrar de manera coherente estas dimensiones, y la AM se presenta como una propuesta teórica con gran potencial en este ámbito.

3. RELACIÓN ENTRE ALFABETIZACIÓN MOTRIZ Y RENDIMIENTO ACADÉMICO

La AM, entendida como una competencia multidimensional que integra capacidades físicas, cognitivas, sociales y psicológicas, ofrece un marco conceptual idóneo para analizar las múltiples vías a través de las cuales el movimiento y la AF pueden contribuir al aprendizaje escolar. En la última década, se ha acumulado un cuerpo creciente de evidencia que sugiere que distintos componentes de la AM se relacionan de forma positiva con indicadores de RA, tanto de manera directa como indirecta.

Desde el dominio físico, se ha documentado que la CM, particularmente la motricidad fina y la coordinación, se asocia con mejoras en funciones cognitivas y en logros académicos. Por ejemplo, niños y niñas con mayor CM tienden a obtener mejores resultados en matemáticas y lectura, en parte porque requieren menos recursos cognitivos para ejecutar tareas motrices, lo cual libera capacidad atencional para afrontar demandas escolares. Asimismo, la ACR ha demostrado estar vinculada con un mejor funcionamiento cerebral, incluyendo cambios estructurales (e.g., mayor grosor cortical) y funcionales (e.g., eficiencia en redes neuronales), especialmente en regiones asociadas a la función ejecutiva. Estos beneficios se traducen en mejoras cognitivas y en un mayor RA.

Sin embargo, las relaciones entre capacidades físicas y RA no parecen responder exclusivamente a mecanismos biológicos o neurológicos. Diversos estudios han propuesto que la práctica de AF y el desarrollo motor también inciden en el bienestar emocional, la autoeficacia y la motivación del alumnado, elementos todos ellos integrados en el dominio psicológico de la AM. Por ejemplo, la percepción de CM y la motivación autónoma se han identificado como mediadores en la relación entre la CM y la participación física, y podrían también actuar como facilitadores del compromiso académico.

Desde el dominio social, el apoyo de los iguales, la participación en actividades cooperativas y el reconocimiento social también han sido señalados como factores que favorecen tanto la implicación en la AF como en el aprendizaje. Estos elementos configuran un entorno emocional y relacional favorable, que potencia el sentido de pertenencia, el disfrute y la persistencia escolar.

El dominio cognitivo, por su parte, guarda una estrecha relación con los procesos que subyacen al aprendizaje académico. La participación en juegos con reglas, tareas de doble tarea o deportes estratégicos activa funciones ejecutivas como la memoria de trabajo, la planificación y el control inhibitorio. Estas experiencias motrices ricas en contenido cognitivo no solo promueven el desarrollo físico, sino que también potencian la competencia intelectual y la autorregulación en el contexto escolar.

Pese a la solidez de estos hallazgos, la mayoría de los estudios existentes han adoptado enfoques centrados en la variable, analizando asociaciones entre factores aislados, lo que limita la comprensión integral del fenómeno. Además, las investigaciones han tendido a centrarse en un único dominio de la AM, especialmente el físico, sin considerar la interacción con otros componentes esenciales como la motivación, la percepción de competencia o la dimensión social.

Frente a esta limitación, el marco de la AM permite una aproximación holística que considera tanto los componentes individuales como su interacción dinámica. Desde esta perspectiva, resulta relevante explorar cómo los distintos dominios se combinan en perfiles específicos de alumnado, y de qué manera estas configuraciones influyen en el rendimiento escolar. Asimismo, cobra sentido investigar la existencia de mecanismos mediadores, en particular de tipo psicológico, que ayuden a explicar cómo las capacidades físicas repercuten en el aprendizaje.

En este contexto, la presente tesis se plantea como una contribución innovadora que busca analizar la relación entre la competencia física y el RC y RA, considerando el papel de las demandas contextuales (como las tareas de doble tarea), de los perfiles multidimensionales y de las autopercepciones y la motivación como posibles mecanismos de mediación. A través de tres estudios complementarios, se pretende avanzar en la comprensión de esta relación desde una lógica integradora, centrada en la persona y coherente con el enfoque de la AM.

4. OBJETIVOS

Por todo lo expuesto en el marco teórico general, en este apartado se presentan los objetivos e hipótesis del presente trabajo de investigación, organizado en tres estudios complementarios.

Hipótesis y objetivo general

En el marco conceptual de la AM, se plantea que el dominio físico se asocia positivamente con el rendimiento cognitivo y académico en la infancia, y que esta relación puede variar en función de las demandas contextuales (como tareas con carga cognitiva), las características individuales (perfiles multidimensionales), así como de factores psicológicos como las autopercepciones y la motivación.

Para contrastar esta hipótesis planteamos el objetivo principal de este trabajo de investigación: Analizar de forma integrada la relación entre la competencia física (CM y ACR) y el rendimiento cognitivo y académico en la infancia, considerando el papel de los factores contextuales (e.g., demandas cognitivas derivadas de la AF y perfiles multidimensionales) y de los mecanismos psicológicos (e.g., autopercepciones y motivación) que podrían influenciar dicha relación, todo ello enmarcado en el modelo holístico de la AM.

Objetivos específicos

Estudio I

Diseñar y validar instrumento que permita evaluar simultáneamente la CM y el rendimiento cognitivo en un entorno ecológico, y analizar cómo las demandas cognitivas influyen en el rendimiento motor de niños y niñas en edad escolar. Asimismo, identificar perfiles de desempeño ante la doble tarea y explorar las diferencias con respecto al rendimiento en tareas simples.

Nuestra hipótesis es que la introducción de demandas cognitivas (doble tarea) en el test de CM afectará significativamente el rendimiento motor de los escolares, disminuyendo su ejecución en comparación con la tarea motriz simple. Asimismo, se hipotetiza que el alumnado se agrupará en perfiles diferenciados en función de su rendimiento combinado (cognitivo y motor) durante la doble tarea, y que estos perfiles presentan diferencias significativas en el desempeño de tareas simples y complejas.

Estudio II

Identificar perfiles de alumnado a partir de la interacción entre los dominios físico, psicológico y social de la AM, y analizar la relación de estos perfiles con el rendimiento cognitivo y académico, adoptando un enfoque centrado en la persona.

Nuestra hipótesis es que se identificarán perfiles diferenciados de alumnado en función de su nivel de AM, considerando los dominios físico, psicológico y social. Asimismo, se plantea que estos perfiles se asociarán de manera distinta con el rendimiento cognitivo y académico, de modo que aquellos con un desarrollo más equilibrado y elevado en los tres dominios de la AM presentarán un mejor rendimiento en ambas esferas.

Estudio III

Analizar la asociación entre las capacidades físicas (CM y ACR) y el rendimiento académico, y examinar el papel mediador de la autopercepción física y académica en esta relación. Asimismo, determinar el valor añadido de la AF como factor explicativo del rendimiento académico.

Nuestra hipótesis es que las autopercepciones psicológicas (i.e., física y académica) mediarán de forma significativa la relación entre las capacidades físicas y el rendimiento académico, y que la inclusión de los niveles de práctica de AF mejorará la capacidad explicativa del modelo.

5. METODOLOGÍA

A continuación, se presentan los tres estudios que conforman el núcleo empírico de esta tesis, cada uno de ellos estructurado con sus respectivos apartados de introducción, metodología, resultados y discusión. Estos estudios han sido diseñados de forma complementaria para abordar, desde distintas perspectivas, la relación entre los dominios de la Alfabetización Motriz y el rendimiento en el contexto escolar.

5.1. Estudio I

5.1.1. Introducción

En el marco de la AM, el dominio físico ha sido históricamente el más evaluado, en parte gracias a la disponibilidad de instrumentos consolidados para valorar la CM en contextos escolares. Sin embargo, el dominio cognitivo ha sido objeto de menor atención, en parte debido a la dificultad de evaluarlo en entornos reales de AF. Las pruebas de funciones ejecutivas, tradicionalmente aplicadas en contextos sedentarios, no permiten captar la interacción dinámica entre las dimensiones motriz y cognitiva que se produce en la práctica educativa y deportiva. Este desfase metodológico limita la comprensión del desarrollo infantil desde una perspectiva verdaderamente holística.

A partir de esta carencia, el primer estudio de la tesis se planteó con un enfoque innovador: integrar demandas cognitivas en un test de CM, generando así una situación de doble tarea que permitiera evaluar simultáneamente el desempeño motor y cognitivo de forma ecológica. Para ello, se diseñó y validó una versión adaptada del *Canadian Agility and Movement Skill Assessment* (CAMSA), denominada CAMSA cognitivo, que incorpora decisiones verbales y visuales durante la ejecución del circuito. Esta propuesta responde tanto a una necesidad científica (evaluar el dominio cognitivo en movimiento) como a una necesidad pedagógica (comprender mejor cómo se comportan los estudiantes ante tareas complejas en Educación Física).

El estudio tuvo como objetivo principal diseñar y validar un instrumento que permita evaluar de forma simultánea la CM y el RC en un entorno ecológico, analizando cómo las demandas cognitivas influyen en el rendimiento motor del alumnado. Además, se propuso identificar perfiles diferenciados de desempeño ante la doble tarea y compararlos con el rendimiento en tareas simples, con el fin de explorar patrones de respuesta en distintos niveles de competencia.

5.1.2.Metodología

Se empleó un diseño transversal con una muestra de 169 estudiantes de Educación Secundaria Obligatoria (edad media = 13.2 años; DT = 0.85), de los cuales el 39.3% eran chicas. El estudio se llevó a cabo durante el curso 2021–2022, en tres centros educativos del área urbana de la provincia de Valencia (Comunidad Valenciana, España). Todos los participantes realizaron cuatro pruebas: la versión original del CAMSA, su adaptación cognitiva (i.e., CAMSA cognitivo), y dos pruebas computarizadas clásicas de memoria de trabajo (i.e., Digit Span y Corsi). Se excluyó del análisis a aquellos estudiantes que, a pesar de participar, presentaban alguna limitación física o cognitiva que afectara el desarrollo normal de las tareas. El estudio fue aprobado por el Comité Ético de la Universitat de València (código 1259844), y se obtuvo consentimiento informado por escrito de las familias, así como asentimiento verbal del alumnado.

Las pruebas se realizaron en dos sesiones separadas por al menos 24 horas, con un diseño contrabalanceado entre clases para minimizar posibles efectos del orden de aplicación. En una de las sesiones se administraron el CAMSA original y el test de Corsi, y en la otra, el CAMSA cognitivo junto al Digit Span. Tanto el CAMSA como su versión cognitiva fueron realizados en el patio escolar, mientras que las pruebas cognitivas se llevaron a cabo en un aula silenciosa con ordenadores portátiles. El software PEBL2 fue utilizado para la administración automatizada de los test.

La evaluación de la CM mediante CAMSA incluyó siete tareas secuenciales (e.g., saltos, deslizamiento, lanzamientos, patadas), valoradas tanto por el tiempo de ejecución (i.e., componente productivo) como por la calidad del patrón motor (i.e., componente procesual). La puntuación total del CAMSA se calculó sumando ambos componentes, con un máximo de 28 puntos. Para el CAMSA cognitivo, se mantuvo esta estructura pero se incorporaron cuatro eventos de toma de decisiones (e.g., discriminación de color, cálculo sencillo, orientación en el espacio de los aros), con los que se registró una puntuación cognitiva adicional (0–5 puntos) (ver *Figure 5. Cognitive CAMSA Schedule*).

Para las pruebas cognitivas en aula, el Digit Span evaluó la memoria de trabajo y el Corsi la memoria visoespacial. Ambos test se presentaron de forma digital, con procedimientos progresivos que aumentaban la longitud de la secuencia a recordar. Se registraron variables como número total de aciertos, amplitud máxima de recuerdo y puntuación de memoria.

Los análisis estadísticos incluyeron comparaciones intraindividuales entre el CAMSA original y su versión cognitiva mediante la prueba de Wilcoxon, así como el cálculo de la interferencia producida por la doble tarea. Posteriormente, se aplicó un análisis de mapas autoorganizados (SOM), utilizando como variables de entrada la puntuación cognitiva, la puntuación motriz y el tiempo de ejecución del CAMSA cognitivo. La configuración óptima se seleccionó tras 1600 iteraciones, y se utilizó un agrupamiento posterior por *k*-medias, estableciendo el número óptimo de perfiles mediante el índice de Davies–Bouldin. Finalmente, se compararon los perfiles identificados en función del sexo y el rendimiento en tareas individuales mediante pruebas de Kruskal–Wallis con corrección de Dunn, y el test de chi-cuadrado para distribuciones de género.

5.1.3. Resultados

Los resultados mostraron que la inclusión de demandas cognitivas redujo significativamente la puntuación total en comparación con el test original, debido principalmente a un incremento en el tiempo de ejecución. Sin embargo, no se observaron diferencias significativas en la calidad de la ejecución motriz (ver *Figure 6. Dual-task interference during the performance of CAMSA test*). Este hallazgo sugiere que la interferencia causada por la doble tarea se manifestó principalmente en términos de eficiencia temporal, sin deterioro generalizado en la competencia técnica.

La variabilidad individual en la respuesta a la doble tarea fue notable. Mientras que el 73% de los participantes obtuvo una puntuación total inferior en la versión cognitiva, un 14% mejoró su rendimiento y un 12% no mostró cambios. En cuanto al tiempo, el 82% tardó más en la versión con carga cognitiva, aunque un 17% fue más rápido. En la ejecución motriz, más de la mitad del alumnado (56%) redujo su puntuación técnica bajo doble tarea, mientras que un 22% la mejoró.

El análisis de perfiles mediante SOM identificó seis configuraciones distintas de rendimiento en la doble tarea, que combinaron de manera variable la puntuación cognitiva, motriz y el tiempo invertido (ver *Figure 7. Results derived from Self-Organizing Map analysis in which performance profiles during cognitive CAMSA*) Algunos perfiles presentaron un alto rendimiento en ambas dimensiones (e.g., perfil 5), mientras que otros destacaron solo en una o mostraron dificultades combinadas (e.g., perfil 1). El análisis de las pruebas en tareas simples reveló diferencias significativas entre los perfiles, confirmando la utilidad del enfoque centrado en la persona.

Existió una disociación entre el rendimiento en pruebas cognitivas tradicionales y el rendimiento cognitivo en movimiento. Algunos perfiles mostraron un desempeño destacado en pruebas estáticas pero reducido en situación de doble tarea, y viceversa (ver *Figure 8. Differences in the variables obtained from original CAMSA, Corsi Block test, and Digit Span test between clusters*).

5.1.4. Discusión

El Estudio 1 aporta evidencia empírica sobre la viabilidad, pertinencia y valor añadido de evaluar de forma integrada el rendimiento motor y cognitivo en contextos escolares mediante situaciones de doble tarea. La adaptación cognitiva del CAMSA se presenta como una herramienta prometedora para este propósito, al permitir una valoración simultánea y ecológica de dos dominios clave de la AM: el físico y el cognitivo.

Los resultados confirman que la interferencia generada por la doble tarea no afecta de manera homogénea al alumnado, y que existen perfiles diferenciados de desempeño ante esta exigencia. Esta variabilidad individual respalda la necesidad de emplear enfoques centrados en la persona, especialmente cuando se pretende comprender cómo interactúan la CM y las funciones ejecutivas en condiciones de mayor complejidad. Asimismo, la disociación observada entre el rendimiento en pruebas cognitivas tradicionales y en movimiento sugiere que el contexto de evaluación modula las capacidades cognitivas expresadas, y que los instrumentos estáticos podrían no capturar adecuadamente las competencias aplicadas en entornos auténticos.

Desde una perspectiva aplicada, los hallazgos ofrecen implicaciones relevantes para la Educación Física escolar. El uso de herramientas como el CAMSA cognitivo puede facilitar una evaluación más formativa, contextualizada y significativa del alumnado, permitiendo al profesorado identificar perfiles con diferentes necesidades y adaptar sus estrategias didácticas en consecuencia. Este tipo de evaluación, además, favorece el desarrollo de competencias cognitivas en contextos reales de acción motriz, y contribuye a romper con modelos evaluativos excesivamente reduccionistas o descontextualizados.

Aunque no se detectaron diferencias estadísticamente significativas por género en la distribución de perfiles, se observaron tendencias relevantes, con una mayor proporción de chicas en los grupos de menor rendimiento motor. Este patrón, ya identificado en investigaciones previas, podría estar influido por factores sociales y contextuales como la menor participación de las niñas en actividades físico-deportivas estructuradas o una percepción negativa de su propia competencia. Estos resultados subrayan la importancia de implementar intervenciones coeducativas que reduzcan la brecha de género en el desarrollo de la AM, fomentando entornos más inclusivos y motivadores.

Finalmente, este estudio establece un precedente metodológico sólido para futuras investigaciones interesadas en integrar los dominios físico y cognitivo en el análisis del desarrollo infantil. El uso combinado de tareas duales, análisis intraindividual y enfoques de clasificación no supervisada permite capturar patrones complejos de interacción, aportando una visión más rica y precisa del funcionamiento infantil en situaciones de movimiento con exigencia cognitiva. Esta aproximación abre nuevas vías para la investigación, la evaluación y la intervención en el ámbito escolar.

5.2. Estudio II

5.2.1. Introducción

El RC en la infancia es un componente clave del desarrollo integral, vinculado al bienestar, la salud mental y el éxito escolar. Este constructo se ha relacionado con múltiples factores individuales y contextuales, entre ellos la participación en AF, la condición física y la CM. Aunque existe evidencia que apoya su influencia positiva sobre la cognición, los resultados no son concluyentes, posiblemente debido a la intervención de otros elementos como la intensidad de la actividad, el tipo de tarea, o factores psicológicos y sociales. En este sentido, variables del dominio psicológico, como la motivación autónoma, la satisfacción de necesidades psicológicas básicas o la percepción de competencia, podrían estar influyendo sobre dicha relación. Asimismo, la práctica de AF, especialmente en contextos grupales, se ve condicionada por el dominio social, incluyendo el apoyo de iguales, docentes o familia, así como factores comunitarios y estructurales.

A pesar de la relevancia de estos tres dominios (i.e., físico, psicológico y social), la mayoría de estudios previos los ha abordado de forma aislada. Además, los enfoques estadísticos tradicionales centrados en la variable presentan limitaciones a la hora de analizar relaciones complejas con múltiples factores. En cambio, los enfoques centrados en la persona, como los análisis de perfiles, permiten identificar combinaciones reales de características individuales y su relación con el rendimiento cognitivo. Por todo ello, el presente estudio se propuso analizar los perfiles de alumnado resultantes de la interacción entre los dominios físico, psicológico y social de la AM, y explorar su asociación con el RC y RA, adoptando una perspectiva holística centrada en la persona.

5.2.2.Metodología

Se empleó un diseño transversal con una muestra final de 194 estudiantes de quinto curso de Educación Primaria (edad media = 10.6 años; DT = 0.45), de los cuales el 48.96% eran chicas. La muestra se obtuvo de seis centros escolares públicos y concertados del área urbana de Valencia, seleccionados aleatoriamente entre aquellos que aceptaron participar y realizar todas las mediciones necesarias. La recogida de datos se realizó a lo largo de una semana por centro, durante el curso escolar 2022–2023. Se recopilaron datos mediante cuestionarios autoinformados, pruebas físicas estandarizadas, pruebas cognitivas objetivas y medidas académicas. Todas las evaluaciones fueron supervisadas por el equipo investigador. El estudio fue aprobado por el Comité Ético de la Universitat de València (código 1564606) y se llevó a cabo conforme a los principios de la Declaración de Helsinki.

La AF se midió de forma objetiva mediante acelerómetros (modelo ActiGraph wGT3X-BT), utilizados durante ocho días consecutivos. Para garantizar la validez del registro, se exigió un mínimo de tres días lectivos y un día de fin de semana con al menos ocho horas de registro diario. Los datos se analizaron con el software Matlab R2022b, aplicando puntos de corte estandarizados para clasificar la intensidad del movimiento en comportamiento sedentario, actividad ligera y AF moderada-vigorosa (AFMV).

Los factores físicos, psicológicos y sociales se evaluaron mediante escalas y cuestionarios previamente validados, agrupados en función de los dominios de la AM (ver *Table 3. Details of the self-reported questionnaires used in the study according to the domain*). Entre las variables autoinformadas se incluyeron la CM percibida, la AM percibida, la motivación intrínseca y regulada, la competencia percibida en Educación Física, el autoconcepto físico, la participación percibida en AF, la identidad social y el clima motivacional percibido.

Las pruebas físicas incluyeron el test CAMSA para evaluar la CM real, la prueba PACER para estimar la condición física (i.e., ACR) y el cálculo del IMC ajustado por edad y sexo.

El RC se midió mediante pruebas tanto objetivas como subjetivas. A nivel objetivo, se administraron tres pruebas: una prueba de fluidez matemática (i.e., operaciones básicas cronometradas), el test Digit Span (i.e., medición de memoria de trabajo) y el test Stroop en su versión informatizada adaptada (i.e., evaluación de funciones ejecutivas como atención selectiva, inhibición y flexibilidad cognitiva). A nivel subjetivo, se recogieron autoinformes sobre la competencia percibida en lengua y matemáticas. El RA se extrajo de las calificaciones finales del curso, proporcionadas por los centros escolares, unificadas en una escala de 0 a 5.

Para el análisis de los datos se aplicó un análisis SOM, con el fin de identificar perfiles de estudiantes en función de las variables físicas, psicológicas y sociales mencionadas. El procedimiento incluyó la creación de una red neuronal de 12 × 6 neuronas entrenadas de forma iterativa (n = 1600 mapas generados con diferentes configuraciones) para garantizar estabilidad y fiabilidad (ver *Figure 4. Flowchart for the unsupervised SOM algorithm*). Posteriormente, se aplicó un análisis de clústeres tipo k-medias sobre los pesos neuronales obtenidos en el SOM, seleccionando el número óptimo de perfiles en función del índice de Davies–Bouldin.

Una vez establecidos los perfiles, se realizaron comparaciones estadísticas entre ellos en cuanto a las variables de RC y RA, utilizando pruebas no paramétricas (Kruskal–Wallis con post-hoc de Dunn-Bonferroni) y análisis de la distribución por género mediante prueba chi-cuadrado. Estas comparaciones permitieron examinar el valor explicativo de los perfiles identificados en relación con el RC y RA.

5.2.3. Resultados

El análisis mediante mapas autoorganizados permitió identificar seis perfiles diferenciados de alumnado a partir de las variables de los dominios físico, psicológico y social. La solución de seis clústeres fue seleccionada como óptima tras aplicar el índice de Davies–Bouldin, y los grupos resultantes se agruparon mediante *k*-medias (ver *Figure 9. Description of results of Self-Organizing Map analysis*).

Los seis perfiles identificados a través del análisis SOM reflejan combinaciones diferenciadas de los tres dominios de la AM. El perfil 1 (*Excellers*) agrupa a estudiantes con puntuaciones elevadas en todos los dominios (i.e., físico, psicológico y social) y un IMC inferior al del resto de grupos. El perfil 2 (*Notables*), el más numeroso, se caracteriza por una combinación inconsistente en el dominio físico (baja AF diaria y condición física, CM media y alto IMC), pero puntuaciones relativamente altas en los dominios psicológico y social, destacando la percepción de conexión en Educación

Física y el disfrute escolar. El perfil 3 (*Resilients*) presenta valores bajos en el dominio físico, excepto en la CM real, que es elevada, y un IMC alto. En los dominios psicológico y social muestran valores moderados, con alta motivación intrínseca y disfrute escolar, aunque baja percepción de relación en Educación Física. El perfil 4 (*Moderates*) se define por puntuaciones medias-bajas en el dominio físico y un IMC bajo, así como valores moderados en los dominios psicológico y social. El perfil 5 (*Strugglers*), el segundo más numeroso, presenta puntuaciones bajas en todos los dominios, salvo en CM real, que es moderada, y un IMC elevado; destaca por ser el grupo con menor bienestar psicológico y social. Por último, el perfil 6 (*Socializers*), con el menor número de participantes, muestra puntuaciones muy bajas en el dominio físico y un IMC muy elevado. Sin embargo, combina niveles bajos o moderados en el dominio psicológico con una elevada motivación y puntuaciones altas en el dominio social, a excepción del autoconcepto físico.

Las diferencias entre clústeres fueron significativas en todas las variables de entrada (ver *Table 4. Cluster effect on input variables*), con tamaños del efecto especialmente elevados en la percepción de CM ($\varepsilon^2 = 0.60$), autoconcepto físico ($\varepsilon^2 = 0.56$), AM percibida ($\varepsilon^2 = 0.55$) y ACR ($\varepsilon^2 = 0.43$). Además, se obtuvieron las estadísticas descriptivas y comparaciones por pares (ver *Table 5. Descriptive statistics of input variables and pairwise comparisons*).

Respecto al RC y RA, se encontraron diferencias significativas entre clústeres únicamente en el rendimiento académico ($H_5 = 18.83$; $p < .002$), pero no en las medidas subjetivas de competencia en matemáticas y lengua. Los análisis post-hoc indicaron que los clústeres 1 (*Excellers*) y 4 (*Moderates*) obtuvieron puntuaciones significativamente superiores al clúster 5 (*Strugglers*) (Figura 3).

En las variables cognitivas objetivas, se encontraron diferencias significativas en fluidez matemática, con puntuaciones más altas en los clústeres 1 y 4 (χ^2 (5) = 28.54; $p < .001$). No se observaron diferencias significativas en la prueba de memoria de trabajo (Digit Span), ni en la mayoría de las variables derivadas del test de Stroop, aunque algunas dimensiones (como el tiempo en la tarea de palabras, la tarea de colores y las respuestas correctas en la tarea de puntos) sí mostraron diferencias entre grupos (ver *Table 6. Cluster effect on Digit Span test and Stroop test variables*). Se obtuvieron también las comparaciones por pares (ver *Table 7. Descriptive statistics of Digit Span test and Stroop test variables and pairwise comparisons*).

Finalmente, se detectaron diferencias significativas por género en la distribución de los perfiles (χ^2 (5) = 21.0; $p < .001$). Los clústeres 1 y 3 presentaron una mayor proporción de chicos, mientras que los clústeres 4, 5 y 6 estuvieron más representados por chicas. El clúster 2 presentó una distribución equilibrada.

5.2.4. Discusión

Este estudio examinó cómo la interacción entre los dominios físico, psicológico y social se relaciona con el RC y RA en la infancia, utilizando un enfoque centrado en la persona. Mediante el análisis de perfiles, se identificaron seis configuraciones distintas de alumnado con niveles de desarrollo diversos en cada uno de estos dominios.

Los perfiles con puntuaciones moderadas o altas en varios dominios (i.e., *Excellers*, *Notables*, *Resilients* y *Moderates*) mostraron un rendimiento cognitivo superior, mientras que aquellos con déficits en uno o más dominios (i.e., *Strugglers* y *Socializers*) presentaron los resultados más bajos. Este patrón sugiere que un desarrollo equilibrado y positivo en los distintos ámbitos favorece el RC, mientras que las carencias acumuladas tienden a limitarlo. En particular, los perfiles con mayor condición física, práctica habitual de AF y menor IMC (especialmente *Excellers*) alcanzaron mejores calificaciones académicas, reforzando la evidencia sobre el papel de la salud física en el RC. Aun así, se observó que ciertos perfiles con desarrollo físico moderado, como *Notables* o *Resilients*, lograban buenos resultados cuando contaban con fortalezas en las dimensiones psicológica o social, lo que indica un efecto compensatorio entre dominios.

Por el contrario, los perfiles con menor motivación, autoconcepto o apoyo social registraron un RC más bajo, incluso en presencia de niveles aceptables de CM. Este hallazgo subraya la importancia de estrategias educativas integrales que fomenten no solo la AF, sino también el desarrollo de la motivación, la autopercepción positiva y el entorno social de los niños y niñas. También se observaron diferencias de género en la distribución de los perfiles, con una mayor representación femenina en aquellos con menor desarrollo físico. Esto plantea la necesidad de ofrecer oportunidades inclusivas de AF adaptadas a una amplia diversidad de intereses, alejadas de estereotipos tradicionales.

Entre las limitaciones del estudio se incluye su diseño transversal, que impide establecer relaciones causales. Asimismo, variables relevantes como el nivel socioeconómico, el descanso o la alimentación no fueron consideradas. Por otro lado, las pruebas cognitivas empleadas, si bien útiles, podrían complementarse en futuros trabajos con instrumentos que aborden un espectro más amplio de funciones ejecutivas.

En conjunto, este estudio proporciona evidencia clara sobre la relevancia de abordar el desarrollo infantil desde una perspectiva holística. Los perfiles identificados muestran que el RC no depende exclusivamente del dominio físico, sino de la combinación y equilibrio con factores psicológicos y sociales. Además, la motivación, el autoconcepto y las relaciones interpersonales emergen como elementos clave que pueden potenciar, o limitar, los beneficios asociados a la AF. Comprender estas configuraciones ofrece una base valiosa para el diseño de intervenciones educativas más ajustadas a las necesidades reales del alumnado. Promover el desarrollo integral desde la Educación Física, las actividades extracurriculares y el entorno familiar puede contribuir a reducir desigualdades, mejorar el bienestar y potenciar el aprendizaje en la infancia. Futuras investigaciones deberían profundizar en el seguimiento longitudinal de estos perfiles, para diseñar estrategias personalizadas que favorezcan trayectorias de desarrollo más equitativas y sostenibles en el tiempo.

5.3. Estudio III

5.3.1. Introducción

La CM y la condición física desempeñan un papel fundamental en el desarrollo infantil, y ambas han sido relacionadas con beneficios para la salud física, mental y académica. Aunque numerosos estudios han demostrado asociaciones positivas entre la ACR y el RA, la evidencia sobre el papel específico de la CM es aún limitada, especialmente cuando se consideran habilidades motrices gruesas. Además, los mecanismos que explican estas relaciones siguen siendo poco concluyentes, con resultados mixtos sobre la mediación de funciones ejecutivas.

Frente a estas inconsistencias, investigaciones recientes han comenzado a explorar el papel de factores psicológicos como mediadores en la relación entre la AF y el RA.

En este sentido, se ha planteado que las autopercepciones, incluyendo la percepción de CM, la motivación autónoma o el autoconcepto académico, podrían desempeñar un papel clave en la conexión entre los dominios físico y académico. Destaca especialmente el concepto de AM percibida como un constructo holístico que integra competencia, motivación, confianza, conocimiento y comprensión para promover la participación a lo largo de la vida.

Bajo esta perspectiva, se plantea que las percepciones psicológicas del alumnado sobre su competencia física pueden influir en su autopercepción académica y, por ende, en su rendimiento. Así, un modelo de mediación serial permitiría explorar si tanto la CM como la ACR influyen en el RA a través de estas autopercepciones físicas y académicas.

Con base en este marco, el presente estudio se propuso tres objetivos principales: (1) analizar la asociación entre la CM y la ACR con el RA; (2) explorar el papel mediador de las autopercepciones físicas y académicas en dicha relación; y (3) examinar si la inclusión de la práctica de AF, como variable predictora, mejora la explicación del RA, considerando la influencia diferenciada de medidas subjetivas (autoinforme) y objetivas (acelerometría).

5.3.2.Metodología

En este estudio transversal participaron un total de 218 estudiantes de quinto curso de Educación Primaria (edad media = 10.53 años; DT = 0.36), procedentes de seis centros escolares de la ciudad de Valencia y su área metropolitana, cuatro de carácter público y dos privados. Todos los participantes presentaban un desarrollo típico, sin dificultades físicas o mentales que impidieran la realización de las pruebas. El estudio fue aprobado por el Comité de Ética de la Universitat de València (referencia UV1259844).

La recogida de datos se realizó a lo largo de una semana en cada centro. Se administraron cuestionarios autoinformados, se realizaron pruebas físicas estandarizadas, se recogieron medidas objetivas de AF mediante acelerometría y se obtuvieron las calificaciones académicas finales de cada alumno. Los cuestionarios se pasaron en dos sesiones de 45 minutos, en días distintos, en el aula habitual del alumnado. Las pruebas físicas se realizaron durante las clases de Educación Física, en el gimnasio o el patio, y fueron dirigidas y supervisadas por el equipo investigador. La AF diaria se registró con acelerómetros ActiGraph wGT3X-BT, que los participantes llevaron durante ocho días consecutivos. Para garantizar la validez de los datos, se estableció como criterio mínimo tres días laborables y un día de fin de semana con al menos ocho horas diarias de uso del dispositivo.

La CM se evaluó mediante el test CAMSA. La ACR se midió mediante la prueba PACER. El RA se obtuvo a través de las calificaciones finales del curso, estandarizadas en una escala de 0 a 5 puntos y promediadas en una nota global. La percepción de CM se recogió mediante la *Pictorial Scale of Perceived Movement Skill Competence*, una escala visual con 13 habilidades básicas, valoradas por el propio alumnado en una escala Likert de 4 puntos. La percepción de ACR se midió mediante la subescala de condición física del *Physical Self-Concept in Children Scale*, centrada en aspectos como fuerza, resistencia, velocidad, flexibilidad y coordinación. La motivación autodeterminada hacia la AF se calculó a partir del índice de autonomía relativa del *Behavioural Regulation in Exercise Questionnaire*, que incluye distintos tipos de regulación motivacional (intrínseca, identificada, introyectada y externa). La percepción de AM se evaluó con el *Physical Literacy in Children Questionnaire*, instrumento que integra los dominios físico, psicológico, social y cognitivo de la AM. Por su parte, la autopercepción del RA se obtuvo mediante tres ítems que evaluaban la percepción general, matemática y lingüística del desempeño escolar.

La AF se midió tanto de forma subjetiva como objetiva. La medida subjetiva se recogió mediante el *Physical Activity Questionnaire for Children*, un cuestionario que evalúa la frecuencia y variedad de la AF semanal en distintos contextos (e.g., recreos, clases de Educación Física, fines de semana). De manera complementaria, la medida objetiva se obtuvo a través de acelerometría, categorizando la AF en tres niveles de intensidad: comportamiento sedentario, AF ligera y AFMV, calculada en minutos diarios. Los datos se procesaron con el software MATLAB R2022b.

Como covariables del estudio se incluyeron el IMC, el sexo y la edad, dadas sus asociaciones previamente documentadas con la CM, la ACR y el RA. Además, según el predictor principal empleado en cada modelo, se controló el efecto cruzado de CM y ACR, con el fin de aislar el efecto específico de cada una sobre el RA.

Los análisis se realizaron con el software IBM SPSS Statistics v.26, estableciendo el nivel de significación en $p < .05$. Se calcularon estadísticos descriptivos (medias y desviaciones típicas) y se comprobó la normalidad mediante la prueba de Kolmogorov-Smirnov e inspección visual. Aunque los datos no seguían una distribución normal, se aplicaron pruebas t para muestras independientes, dada su robustez y el tamaño muestral. También se calcularon los tamaños del efecto con el estadístico d de Cohen. Las correlaciones entre variables se estimaron con coeficientes de Pearson, clasificándose como muy bajas ($r < .20$), bajas (.20–.39), moderadas (.40–.69), altas (.70–.79) o muy altas ($\geq .80$).

Se llevó a cabo un análisis preliminar para determinar cuál de las autopercepciones físicas disponibles era la más adecuada para ser incluida como mediador. Para ello, se estimó un modelo de mediación paralela (modelo 4), en el que CM o ACR actuaban como predictores, la autopercepción del RA como variable dependiente, y cuatro posibles mediadores del dominio físico se introdujeron de forma simultánea: autopercepción de CM, autopercepción de condición física, motivación autodeterminada hacia la AF y percepción de AM.

Para analizar los efectos indirectos, se aplicaron modelos de mediación múltiple (paralela y seriada) con el macro PROCESS para SPSS (modelo 6), utilizando remuestreo bootstrap BCa con 10.000 réplicas. Se consideró significativo cualquier efecto indirecto cuyo intervalo de confianza del 95% no incluyera el cero.

El análisis principal consistió en un modelo de mediación en serie de tres pasos, donde se hipotetizó que CM o ACR (predictor) influirían en el RA (variable dependiente) a través de dos mediadores organizados de forma secuencial: una autopercepción en el dominio físico (M1) y una autopercepción en el dominio académico (M2). El modelo se aplicó en dos versiones: una en la que CM fue la variable predictora (modelo b1) y otra en la que lo fue la ACR (modelo b2). En ambos casos, se incluyeron como covariables el sexo, la edad e IMC, además de controlar la variable física alternativa (i.e., cuando CM era el predictor, se controló la ACR y viceversa) con el fin de aislar el efecto específico de cada componente físico. Los modelos de mediación en serie proporcionan tanto el efecto total como el efecto directo y los distintos efectos indirectos. Se estimaron trayectorias de mediación simples (i.e., X → M1 → Y, y X → M2 → Y) así como la trayectoria completa en serie (i.e., X → M1 → M2 → Y), que permite valorar el efecto acumulado de los dos mediadores ordenados jerárquicamente.

Además, se implementó un segundo modelo de mediación en serie más amplio, de cuatro pasos, incorporando la AF (i.e., autoinformada o AFMV) como variable predictora inicial. Este modelo permitió analizar si el efecto de la AF sobre el RA estaba mediado secuencialmente por CM o ACR (primer mediador), una autopercepción física (segundo mediador) y una autopercepción académica (tercer mediador). Se aplicaron cuatro variantes del modelo, combinando las dos formas de medición de la AF (i.e., autoinformada o AFMV) con los dos predictores físicos posibles (i.e., CM, ACR).

5.3.3. Resultados

Se obtuvieron los análisis descriptivos y correlacionales de las variables (ver *annex 3*, *annex 4*). Además, se llevaron a cabo dos modelos de mediación paralela con CM y ACR como variables predictoras, percepción del RA como variable dependiente y cuatro variables de autopercepción física como mediadores paralelos. En ambos modelos, únicamente la AM percibida resultó ser un mediador significativo (ver *annex 5*, *annex 6*).

Se aplicaron dos modelos de mediación serial (modelo 6 de PROCESS) para analizar el efecto de la CM (modelo b1) y de la ACR (modelo b2) sobre el rendimiento académico (RA), con la percepción de AM y la autopercepción académica como mediadores secuenciales.

En el modelo b1, la CM mostró un efecto indirecto significativo sobre el RA a través de los dos mediadores en cadena (efecto indirecto total: 0.06; IC 95% = 0.03–0.11) [ver *Figure 11. Serial mediation model of the relationship between Motor Competence and Academic Achievement through Perceived Physical Literacy and Self-Perceived Academic*

Achievement (model b1)]. El efecto total fue significativo (c = 0.17; p = .029), pero el efecto directo no lo fue, lo que indica una mediación completa. Todas las rutas individuales fueron significativas, excepto las trayectorias directas entre CM y percepción del RA, y entre AM percibida y RA. El modelo explicó el 24% de la varianza en el RA (R^2 = .24; p < .001).

En el modelo b2, con ACR como predictor, también se observó un efecto indirecto significativo (efecto indirecto total: 0.003; IC 95% = 0.001–0.006), aunque de menor magnitud [ver *Figure 12. Serial mediation model of the relationship between Cardiorespiratory Fitness and Academic Achievement through Perceived Physical Literacy and Self-Perceived Academic Achievement (model b2)*]. Ni el efecto total ni el directo fueron significativos, indicando mediación inconsistente. Al igual que en el modelo anterior, todas las rutas individuales de mediación fueron significativas excepto las rutas directas finales. Este modelo también explicó el 24% de la varianza del RA.

Se exploró si la AF, medida tanto de forma subjetiva como objetiva, mejoraba la explicación del RA al incluirla como predictor en un modelo de mediación serial de cuatro pasos: AF → CM/ACR → AM percibida → RA percibido → RA.

En el modelo c1 (AF autoinformada como predictor, CM como primer mediador), se observó un efecto indirecto significativo (0.010; IC 95% = 0.002–0.021), a pesar de que los efectos total y directo no lo fueron. Todas las rutas intermedias fueron significativas [ver *Figure 13. Serial mediation model of the relationship between Self-Reported Physical Activity and Academic Achievement through Motor Competence, Perceived Physical Literacy and Self-Perceived Academic Achievement (model c1)*]. Este modelo explicó nuevamente un 24% de la varianza en el RA. En contraste, el modelo c2 (AF autoinformada → ACR) no mostró efectos indirectos significativos, salvo una mediación incompleta a través de las percepciones: AF → AM percibida → percepción académica → RA (0.11; IC 95% = 0.06–0.18) (ver *annex 7*).

Cuando se introdujo la AF objetiva (acelerometría), los resultados se invirtieron. En el modelo c4 (AFMV → ACR), se observó un efecto indirecto significativo (0.0005; IC 95% = 0.0001–0.001), con todas las rutas individuales significativas y sin efectos directos ni totales [ver *Figure 14. Serial mediation model of the relationship between Moderate to Vigorous Physical Activity and Academic Achievement through Cardiorespiratory Fitness, Perceived Physical Literacy and Self-Perceived Academic Achievement (model c4)*]. También en este caso se explicó el 24% de la varianza del RA. En cambio, el modelo c3 (AFMV → CM) no mostró ningún efecto significativo, directo ni indirecto (ver *annex 8*).

En conjunto, estos resultados sugieren que la AF se relaciona con el RA mediante trayectorias diferenciadas, dependiendo del tipo de medición utilizada y del dominio físico involucrado.

5.3.4. Discusión

El presente estudio exploró cómo la CM y la ACR se relacionan con el RA en la infancia, examinando el papel mediador de variables psicológicas como la percepción de AM (AM percibida) y la percepción del RA. Los resultados respaldan un modelo en el que las autopercepciones actúan como mecanismos clave en la relación entre el dominio físico y el académico, particularmente cuando se considera la AM como mediador.

Los análisis iniciales identificaron la AM percibida como el único mediador significativo entre las variables físicas (CM y ACR) y el RA percibido, por encima de otras autopercepciones más específicas. Esta evidencia refuerza su utilidad como puente psicológico entre el desarrollo físico y el académico, superando modelos previos centrados exclusivamente en funciones ejecutivas.

El modelo de mediación serial reveló que la CM influye en el RA a través de las autopercepciones físicas y académicas, mostrando un efecto indirecto significativo y ausencia de efecto directo, lo que indica mediación completa. Por otra parte, en el caso de la ACR, aunque se observaron rutas significativas, el efecto indirecto fue más débil y el total no alcanzó significación, lo que sugiere que esta relación podría operar mediante otros mecanismos, como adaptaciones fisiológicas o cognitivas no capturadas por el modelo propuesto.

Al incorporar la AF como variable predictora en un modelo de cuatro pasos, se evidenciaron diferencias en función del tipo de medición. La AF autoinformada mostró un efecto mediado significativo cuando la CM fue el primer mediador, mientras que la AF medida objetivamente (i.e., AFMV) generó un efecto similar solo cuando la ACR ocupó esa posición. Estas trayectorias diferenciadas revelan que la relación entre AF y RA depende de cómo se mide la AF y del tipo de competencia física involucrada. En este sentido, la AF autoinformada parece reflejar aspectos cualitativos como variedad, intencionalidad o autoconfianza, más relacionados con la CM, mientras que la AFMV se vincula directamente con la ACR a través de mecanismos fisiológicos derivados de la intensidad y duración del movimiento.

Este estudio aporta un enfoque novedoso al demostrar que las autopercepciones físicas y académicas son piezas clave en la comprensión del vínculo entre movimiento y rendimiento escolar. La inclusión de la AM percibida como mediador central ofrece una perspectiva integradora que trasciende los modelos tradicionales y se alinea con los enfoques contemporáneos sobre el desarrollo integral en la infancia. La combinación de medidas objetivas y subjetivas de AF fortalece la validez ecológica del estudio y resalta la necesidad de considerar múltiples herramientas de evaluación para captar los distintos matices del comportamiento motor.

Entre las limitaciones destaca el diseño transversal, que impide establecer relaciones causales. También deben considerarse posibles sesgos derivados de la pérdida de datos en la acelerometría. A pesar de que los modelos explicaron hasta un 24% de la varianza del RA, queda una proporción significativa sin explicar, lo que sugiere la necesidad de incluir en futuras investigaciones factores contextuales y ecológicos como el entorno familiar, escolar y comunitario.

En conclusión, los resultados destacan la importancia de integrar dimensiones físicas, cognitivas y psicosociales al abordar la relación entre el movimiento y el aprendizaje. Desde una perspectiva aplicada, las intervenciones deberían ir más allá de la mejora de la CM y la ACR, incorporando estrategias que potencien la confianza, la percepción de competencia y la motivación del alumnado en relación con el movimiento. Programas de Educación Física inclusivos, desarrollo estructurado de habilidades motrices y retroalimentación constructiva pueden contribuir a fortalecer las autopercepciones y, en última instancia, mejorar los resultados académicos. Asimismo, la adopción de metodologías mixtas para evaluar la AF permitirá una comprensión más completa del papel que desempeña el movimiento en los contextos educativos.

6. CONCLUSIONES GENERALES

El presente trabajo de investigación ha contribuido a ampliar el conocimiento actual sobre las interacciones entre los distintos dominios de la AM y su desarrollo durante la infancia. Los resultados obtenidos refuerzan la necesidad de seguir profundizando en este constructo multidimensional, en sus elementos constitutivos y en las relaciones dinámicas que se establecen entre ellos a lo largo del tiempo. En particular, los tres estudios empíricos que conforman esta tesis han permitido avanzar en la comprensión del vínculo entre los dominios físico y cognitivo, así como en la relación más amplia entre la AM, el RC y el RA.

Los hallazgos destacan varios aspectos clave. En primer lugar, se ha demostrado que la inclusión de demandas cognitivas en tareas motrices influye significativamente en el rendimiento motor, lo que constituye un aspecto esencial a tener en cuenta en futuras investigaciones sobre la CM en población infantil. En segundo lugar, se han identificado diferencias individuales y trayectorias personales en el desarrollo de la AM, lo que pone de relieve la relevancia de enfoques personalizados en contextos educativos. Por último, se ha evidenciado que factores psicológicos, en concreto, la percepción de AM y el RA percibido, desempeñan un papel mediador en la relación entre las capacidades físicas (i.e., CM, ACR) y el RA. Estos resultados permiten una comprensión más matizada de cómo interactúan los distintos dominios y abren nuevas vías para el diseño de intervenciones integradas que promuevan simultáneamente el desarrollo físico y académico del alumnado.

A continuación, se presentan las principales conclusiones específicas de cada uno de los estudios realizados:

Estudio I

El primer estudio permitió desarrollar y validar una versión cognitiva del test CAMSA, que posibilita la evaluación simultánea de la CM y del RC en condiciones de doble tarea. El cognitive CAMSA demostró ser un instrumento factible, con validez ecológica y adecuado para su uso en contextos educativos. Mediante un enfoque basado en análisis SOM, se identificaron perfiles diferenciados de rendimiento, lo que puso de manifiesto la existencia de diferencias individuales en la manera en que las demandas cognitivas afectan al desempeño motriz y cognitivo. Mientras algunos estudiantes mantuvieron un rendimiento estable entre condiciones simples y de doble tarea, otros mostraron variaciones significativas, especialmente en el RC. Estos resultados avalan el uso del cognitive CAMSA como herramienta diagnóstica y pedagógica para diseñar intervenciones ajustadas a los perfiles individuales del alumnado en contextos escolares y deportivos.

Estudio II

El segundo estudio adoptó un enfoque centrado en la persona para identificar perfiles de AM a partir de la interacción entre los dominios físico, psicológico y social. Los perfiles obtenidos mostraron efectos diferenciados en los niveles de AF diaria, en las autopercepciones y en el rendimiento físico. El alumnado con mayores niveles de AF y características psicológicas y sociales más positivas presentó un mejor RC, en contraste con aquellos perfiles con puntuaciones más bajas en dichos dominios. Estos hallazgos subrayan la naturaleza multidimensional del desarrollo cognitivo y ponen de relieve la importancia de diseñar estrategias educativas sensibles a la diversidad de perfiles del alumnado. La implementación de programas individualizados que potencien las fortalezas personales y aborden las necesidades específicas puede favorecer el desarrollo integral del alumnado en el contexto escolar.

Estudio III

El tercer estudio mostró que la relación entre la CM y la ACR con el RA se explica principalmente mediante mecanismos de mediación en cadena que implican autopercepciones físicas y académicas. Aunque no se observó una asociación directa entre la AF (i.e, AF autoinformada, AFMV) y el RA, sí se detectaron efectos indirectos a través de modelos de mediación serial que incluían el rendimiento físico (i.e., CM, ACR), la percepción de AM y el RA percibido. Las trayectorias diferenciales observadas indicaron que la AF autoinformada se asoció con la CM, mientras que la AFMV se relacionó con la ACR, y ambas rutas culminaron en el RA a través de mecanismos psicológicos. Estos resultados destacan la relevancia de las autopercepciones como elementos clave en la comprensión del vínculo entre los dominios físico y académico, y respaldan una visión holística del desarrollo infantil en la que la AM desempeña un papel central como mecanismo psicológico articulador. Se recomienda el uso de enfoques multimétodo en la evaluación de la AF para captar con mayor precisión estas interacciones complejas.

ANNEXES

Annex 1. Descriptive data of the variables (study 1)

Test	Variable		Boys	Girls	Total
Cognitive CAMSA	*Cognitive score*	Mean	4,04	3,81	3,92
		Median	4	4	4
		SD	1,04	1,01	1,08
		IQR	2	2	2
	Motor skill score	Mean	10,4	9,03	9,83
		Median	11	9	10
		SD	2,51	2,34	2,52
		IQR	3	3,25	4
	Time (s)	Mean	24,7	26,5	25,4
		Median	22,8	25,4	23,9
		SD	7,45	7,7	7,29
		IQR	7,07	8,93	8,42
Original CAMSA	*Motor skill score*	Mean	10,9	9,79	10,4
		Median	11	10	10
		SD	2,12	2,03	2,1
		IQR	2,25	2	3
	Time (s)	Mean	22,2	23,5	22,8
		Median	21,1	21,9	21,5
		SD	5,58	6,19	5,66
		IQR	7,21	6,76	6,37
	Total Score	Mean	17,4	15,7	16,6
		Median	17	16	17
		SD	4,77	4,54	4,63
		IQR	8	6	7
Corsi Block	*Total correct trials*	Mean	7,7	7,09	7,45
		Median	8	7	8
		SD	2,25	2,04	2,21
		IQR	2	2	3
	Block Span	Mean	5,7	5,25	5,53
		Median	5,5	5	5
		SD	1,51	1,49	1,57
		IQR	1	1	1
	Memory Span	Mean	4,88	4,41	4,69
		Median	5	4,5	5
		SD	1,21	1,25	1,27
		IQR	1,13	1	1,5
Digit Span	*Total number of correct sequences*	Mean	5,63	5,07	5,38
		Median	5,5	5	5
		SD	2,15	2,28	2,15
		IQR	2	3	3
	Memory Span	Mean	5,58	5,1	5,37
		Median	5	5	5
		SD	1,32	1,35	1,31
		IQR	2	2	1

Annex 2. Pairwise comparisons and effect sizes between clusters (study 1)

Test	Variable	Cluster	Cluster	n1	n2	statistic	p	p.adj	R-effect size
Cognitive CAMSA	*Cognitive score*	1	2	34	23	-2,22	0,03	0,39	-0,29
		1	3	34	27	5,17	0,00	0,00	0,66
		1	4	34	16	-0,33	0,74	1,00	-0,05
		1	5	34	53	8,43	0,00	0,00	0,90
		1	6	34	16	2,25	0,02	0,37	0,32
		2	3	23	27	6,81	0,00	0,00	0,96
		2	4	23	16	1,54	0,12	1,00	0,25
		2	5	23	53	9,82	0,00	0,00	1,13
		2	6	23	16	3,94	0,00	0,00	0,63
		3	4	27	16	-4,54	0,00	0,00	-0,69
		3	5	27	53	2,20	0,03	0,42	0,25
		3	6	27	16	-2,06	0,04	0,59	-0,31
		4	5	16	53	6,84	0,00	0,00	0,82
		4	6	16	16	2,21	0,03	0,41	0,39
		5	6	53	16	-4,11	0,00	0,00	-0,49
	Motor skill score	1	2	34	23	2,13	0,03	0,50	0,28
		1	3	34	27	1,63	0,10	1,00	0,21
		1	4	34	16	5,91	0,00	0,00	0,84
		1	5	34	53	7,93	0,00	0,00	0,85
		1	6	34	16	6,67	0,00	0,00	0,94
		2	3	23	27	-0,54	0,59	1,00	-0,08
		2	4	23	16	3,74	0,00	0,00	0,60
		2	5	23	53	4,67	0,00	0,00	0,54
		2	6	23	16	4,45	0,00	0,00	0,71
		3	4	27	16	4,35	0,00	0,00	0,66
		3	5	27	53	5,59	0,00	0,00	0,62
		3	6	27	16	5,08	0,00	0,00	0,77
		4	5	16	53	-0,18	0,86	1,00	-0,02
		4	6	16	16	0,65	0,51	1,00	0,12
		5	6	53	16	0,98	0,33	1,00	0,12
	Time (s)	1	2	34	23	-2,95	0,00	0,05	-0,39
		1	3	34	27	-4,27	0,00	0,00	-0,55
		1	4	34	16	-4,04	0,00	0,00	-0,57
		1	5	34	53	-9,71	0,00	0,00	-1,04
		1	6	34	16	-6,48	0,00	0,00	-0,92
		2	3	23	27	-1,08	0,28	1,00	-0,15
		2	4	23	16	-1,32	0,19	1,00	-0,21
		2	5	23	53	-5,36	0,00	0,00	-0,61
		2	6	23	16	-3,58	0,00	0,01	-0,57
		3	4	27	16	-0,39	0,69	1,00	-0,06
		3	5	27	53	-4,37	0,00	0,00	-0,49
		3	6	27	16	-2,73	0,01	0,09	-0,42
		4	5	16	53	-3,19	0,00	0,02	-0,38
		4	6	16	16	-2,09	0,04	0,55	-0,37
		5	6	53	16	0,60	0,55	1,00	0,07

Annex 2. Pairwise comparisons and effect sizes between clusters (study 1) (continued)

Test	Variable	Cluster	Cluster	n1	n2	statistic	p	p.adj	R-effect size
Original CAMSA	*Motor skill score*	1	2	34	23	1,92	0,05	0,82	0,25
		1	3	34	27	1,72	0,09	1,00	0,22
		1	4	34	16	4,23	0,00	0,00	0,60
		1	5	34	53	5,87	0,00	0,00	0,63
		1	6	34	16	4,47	0,00	0,00	0,63
		2	3	23	27	-0,27	0,79	1,00	-0,04
		2	4	23	16	2,35	0,02	0,28	0,38
		2	5	23	53	3,09	0,00	0,03	0,35
		2	6	23	16	2,57	0,01	0,15	0,41
		3	4	27	16	2,66	0,01	0,12	0,41
		3	5	27	53	3,59	0,00	0,01	0,40
		3	6	27	16	2,89	0,00	0,06	0,44
		4	5	16	53	0,03	0,98	1,00	0,00
		4	6	16	16	0,20	0,84	1,00	0,04
		5	6	53	16	0,23	0,82	1,00	0,03
	Time (s)	1	2	34	23	-2,17	0,03	0,45	-0,29
		1	3	34	27	-2,93	0,00	0,05	-0,38
		1	4	34	16	-2,77	0,01	0,08	-0,39
		1	5	34	53	-8,26	0,00	0,00	-0,89
		1	6	34	16	-5,16	0,00	0,00	-0,73
		2	3	23	27	-0,60	0,55	1,00	-0,08
		2	4	23	16	-0,78	0,43	1,00	-0,13
		2	5	23	53	-4,93	0,00	0,00	-0,57
		2	6	23	16	-3,00	0,00	0,04	-0,48
		3	4	27	16	-0,27	0,79	1,00	-0,04
		3	5	27	53	-4,48	0,00	0,00	-0,50
		3	6	27	16	-2,56	0,01	0,16	-0,39
		4	5	16	53	-3,42	0,00	0,01	-0,41
		4	6	16	16	-2,04	0,04	0,61	-0,36
		5	6	53	16	0,88	0,38	1,00	0,11
	Total score	1	2	34	23	2,24	0,03	0,38	0,30
		1	3	34	27	2,74	0,01	0,09	0,35
		1	4	34	16	3,91	0,00	0,00	0,55
		1	5	34	53	8,72	0,00	0,00	0,93
		1	6	34	16	5,77	0,00	0,00	0,82
		2	3	23	27	0,36	0,72	1,00	0,05
		2	4	23	16	1,78	0,07	1,00	0,29
		2	5	23	53	5,25	0,00	0,00	0,60
		2	6	23	16	3,52	0,00	0,01	0,56
		3	4	27	16	1,52	0,13	1,00	0,23
		3	5	27	53	5,12	0,00	0,00	0,57
		3	6	27	16	3,31	0,00	0,01	0,50
		4	5	16	53	2,56	0,01	0,16	0,31
		4	6	16	16	1,60	0,11	1,00	0,28
		5	6	53	16	-0,58	0,56	1,00	-0,07

Annex 2. Pairwise comparisons and effect sizes between clusters (study 1) (continued)

Test	Variable	Cluster	Cluster	n1	n2	statistic	p	p.adj	R-effect size
Corsi Block	*Total correct trials*	1	2	34	23	2,04	0,04	0,62	0,27
		1	3	34	27	1,03	0,30	1,00	0,13
		1	4	34	16	2,78	0,01	0,08	0,39
		1	5	34	53	3,59	0,00	0,00	0,38
		1	6	34	16	2,41	0,02	0,24	0,34
		2	3	23	27	-1,01	0,31	1,00	-0,14
		2	4	23	16	0,89	0,37	1,00	0,14
		2	5	23	53	0,95	0,34	1,00	0,11
		2	6	23	16	0,55	0,58	1,00	0,09
		3	4	27	16	1,83	0,07	1,00	0,28
		3	5	27	53	2,21	0,03	0,40	0,25
		3	6	27	16	1,48	0,14	1,00	0,23
		4	5	16	53	-0,19	0,85	1,00	-0,02
		4	6	16	16	-0,31	0,75	1,00	-0,06
		5	6	53	16	-0,20	0,84	1,00	-0,02
	Block span	1	2	34	23	2,01	0,04	0,67	0,27
		1	3	34	27	1,50	0,13	1,00	0,19
		1	4	34	16	2,53	0,01	0,17	0,36
		1	5	34	53	3,85	0,00	0,00	0,41
		1	6	34	16	2,10	0,04	0,53	0,30
		2	3	23	27	-0,55	0,58	1,00	-0,08
		2	4	23	16	0,69	0,49	1,00	0,11
		2	5	23	53	1,22	0,22	1,00	0,14
		2	6	23	16	0,29	0,77	1,00	0,05
		3	4	27	16	1,21	0,23	1,00	0,18
		3	5	27	53	1,94	0,05	0,78	0,22
		3	6	27	16	0,79	0,43	1,00	0,12
		4	5	16	53	0,28	0,78	1,00	0,03
		4	6	16	16	-0,37	0,71	1,00	-0,07
		5	6	53	16	-0,73	0,46	1,00	-0,09
	Memory span	1	2	34	23	2,07	0,04	0,58	0,27
		1	3	34	27	0,78	0,44	1,00	0,10
		1	4	34	16	2,77	0,01	0,08	0,39
		1	5	34	53	3,19	0,00	0,02	0,34
		1	6	34	16	2,36	0,02	0,28	0,33
		2	3	23	27	-1,26	0,21	1,00	-0,18
		2	4	23	16	0,87	0,38	1,00	0,14
		2	5	23	53	0,57	0,57	1,00	0,07
		2	6	23	16	0,48	0,63	1,00	0,08
		3	4	27	16	2,03	0,04	0,64	0,31
		3	5	27	53	2,11	0,03	0,52	0,24
		3	6	27	16	1,63	0,10	1,00	0,25
		4	5	16	53	-0,49	0,62	1,00	-0,06
		4	6	16	16	-0,36	0,72	1,00	-0,06
		5	6	53	16	0,05	0,96	1,00	0,01

Annex 2. Pairwise comparisons and effect sizes between clusters (study 1) (continued)

Test	Variable	Cluster	Cluster	n1	n2	statistic	p	p.adj	R-effect size
Digit Span	*Total number of correct sequences*	1	2	34	23	1,34	0,18	1,00	0,18
		1	3	34	27	2,30	0,02	0,32	0,29
		1	4	34	16	1,61	0,11	1,00	0,23
		1	5	34	53	2,80	0,01	0,08	0,30
		1	6	34	16	2,10	0,04	0,54	0,30
		2	3	23	27	0,82	0,41	1,00	0,12
		2	4	23	16	0,39	0,69	1,00	0,06
		2	5	23	53	1,02	0,31	1,00	0,12
		2	6	23	16	0,85	0,40	1,00	0,14
		3	4	27	16	-0,33	0,74	1,00	-0,05
		3	5	27	53	0,09	0,92	1,00	0,01
		3	6	27	16	0,13	0,89	1,00	0,02
		4	5	16	53	0,45	0,66	1,00	0,05
		4	6	16	16	0,42	0,68	1,00	0,07
		5	6	53	16	0,07	0,94	1,00	0,01
	Memory Span	1	2	34	23	0,90	0,37	1,00	0,12
		1	3	34	27	2,43	0,02	0,23	0,31
		1	4	34	16	2,10	0,04	0,54	0,30
		1	5	34	53	2,79	0,01	0,08	0,30
		1	6	34	16	2,33	0,02	0,30	0,33
		2	3	23	27	1,35	0,18	1,00	0,19
		2	4	23	16	1,20	0,23	1,00	0,19
		2	5	23	53	1,48	0,14	1,00	0,17
		2	6	23	16	1,42	0,16	1,00	0,23
		3	4	27	16	0,03	0,98	1,00	0,00
		3	5	27	53	-0,05	0,96	1,00	-0,01
		3	6	27	16	0,25	0,80	1,00	0,04
		4	5	16	53	-0,08	0,94	1,00	-0,01
		4	6	16	16	0,20	0,84	1,00	0,04
		5	6	53	16	0,33	0,74	1,00	0,04

Annex 3. Table S1. Children's characteristics from study 3 by sex (study 3)

Variables	All (n=218) M ± SD	Boys (n=106) M ± SD	Girls (n=112) M ± SD	*t*	df	P-value	Effect Size (d)
1. Age	10.53±0.36	10.53±0.4	10.52±0.33	0.2	216.00	0.84	0.03
2. BMI	65.47±29.12	66.62±29	64.37±29.32	0.57	216.00	0.57	0.08
3. Perceived Motor Competence	3.00±0.53	3.13±0.5	2.87±0.52	3.81	216.00	**<0.01**	0.52
4. Perceived Physical Fitness	2.91±0.58	3.01±0.55	2.81±0.6	2.69	216.00	**0.01**	0.37
5. Self-determined Motivation for PA	6.11±2.53	6.05±2.44	6.18±2.63	-0.39	216.00	0.7	-0.05
6. Perceived Physical Literacy	3.08±0.49	3.1±0.5	3.06±0.48	0.67	216.00	0.5	0.09
7. Motor Competence	2.02±0.75	2.19±0.81	1.86±0.66	3.32	202.54	**<0.01**	0.45
8. Cardiorespiratory Fitness	28.23±16.99	32.79±17.93	23.91±14.88	3.97	204.31	**<0.01**	0.54
9. Self-Perception of Academic Achievement	11.68±2.23	11.84±2.25	11.54±2.21	1.00	216.00	0.32	0.14
10. Academic Achievement	4.02±0.75	3.98±0.76	4.05±0.75	-0.67	216.00	0.5	-0.09
11. Self-Reported PA	3.04±0.66	3.27±0.65	2.83±0.6	5.2	216.00	**<0.01**	0.70
	All (n=148) M ± SD	**Boys (n=74) M ± SD**	**Girls (n=74) M ± SD**				
12. Moderate to Vigorous PA	44.64±21.71	53.17±23.42	36.11±15.91	5.18	128.57	**<0.01**	0.85

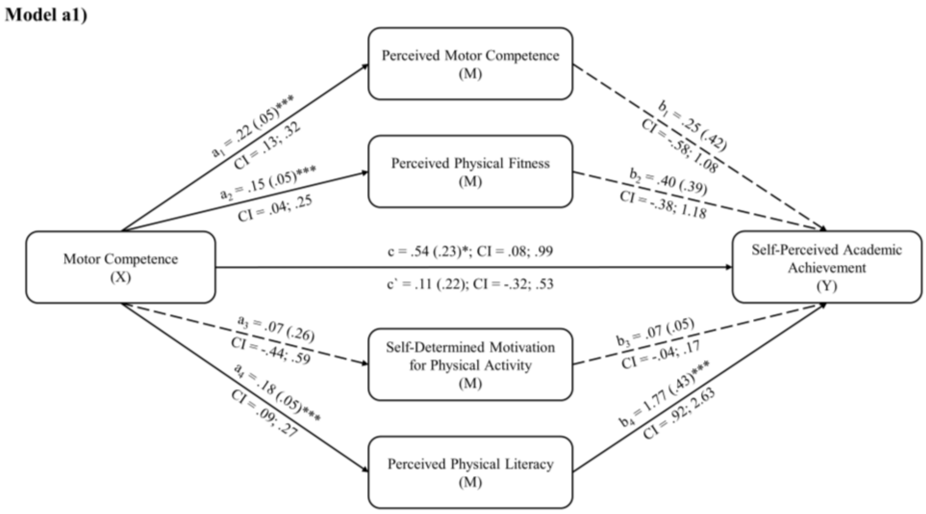
Note. 1: Expressed in years; 2: Expressed in percentage; 3: Scores range from 1 to 4; 4: Scores range from 1 to 5; 5: Scores range from -12 to 12; 6: Scores range from 1 to 5; 7: Scores range from 1 to 5; 8: Expressed in completed laps; 9: Scores range from 3 to 15; 10: Scores range from 1 to 5; 11: Scores range from 1 to 5; 12: Expressed in minutes. P-values that indicate differences between boys and girls are marked in bold. The *t* value corresponds to the independent samples *t*-test used to compare means between groups. SD: Standard deviation; BMI: body mass index; (y): years; df: degrees of freedom; d: Cohen's d.

Annex 4. Table S2. Bivariate correlations between study 3 variables (study 3)

	1	2	3	4	5	6	7	8	9
1. Perceived Motor Competence	-								
2. Perceived Physical Fitness	.747**								
3. Self-determined Motivation for PA	.084	.181**							
4. Perceived Physical Literacy	.679**	.721**	.154*						
5. Motor Competence	.421**	.355**	.082	.397**					
6. Cardiorespiratory Fitness	.329**	.415**	.161*	.395**	.489**				
7. Self-Perception of Academic Achievement	.394**	.408**	.134*	.48**	.205**	.12			
8. Academic Achievement	.094	.168*	.061	.186**	.206**	.188**	.426**		
9. Self-Reported PA	.486**	.465**	.147*	.471**	.332**	.301**	.219**	.025	
10. Moderate to Vigorous PA	.198*	.169*	.049	.143	.276**	.411**	-.043	.016	.229**

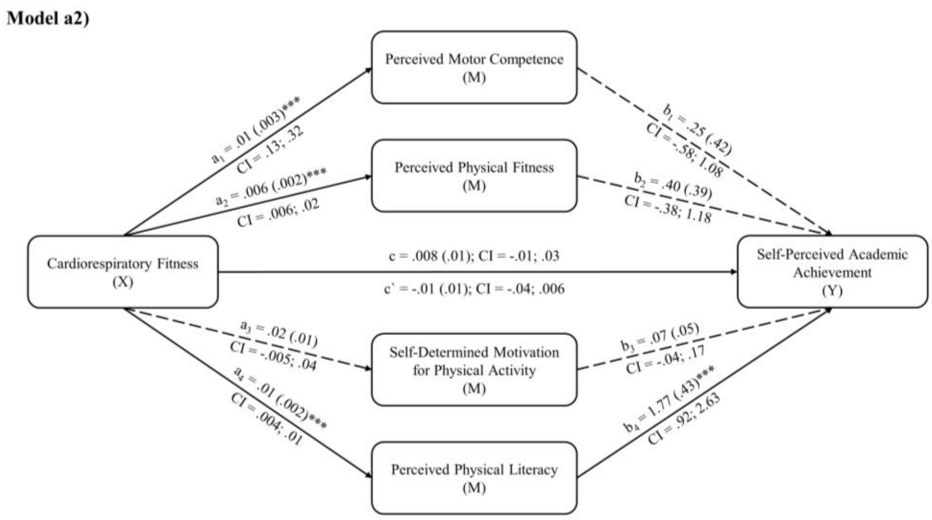
Note. PA=Physical Activity. ** Indicates p-value <.01; * indicates p-value <.05.

Annex 5. Figure S1. Simple mediation model of the indirect effects of Motor Competence on Self-Perceived Academic Achievement (model a1) (study 3)



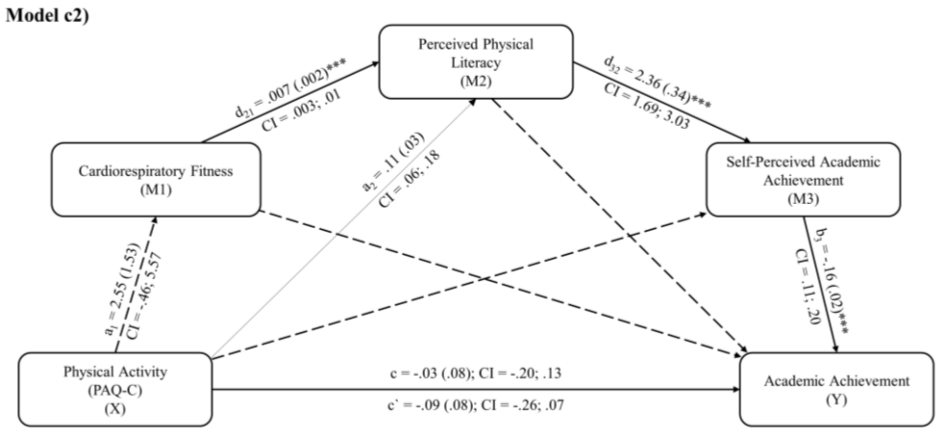
Note. n=218; X: predictor; Y: outcome; M: mediator; CI: confidence intervals; Significant effect — continuous lines; non-significant effect — dashed lines; *p < .05; **p < .005; ***p < .001.

Annex 6. Figure S2. Simple mediation model of the indirect effects of Cardiorespiratory Fitness on Self-Perceived Academic Achievement (model a2) (study 3)



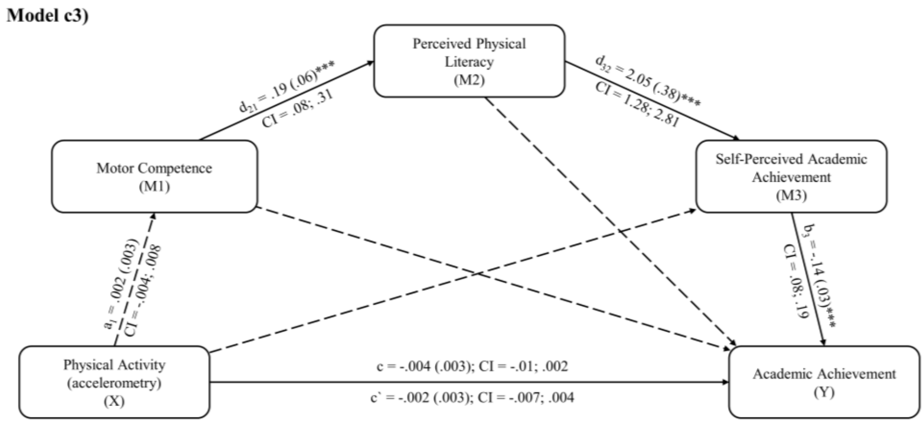
Note. n=218; X: predictor; Y: outcome; M: mediator; CI: confidence interval; Significant effect — continuous lines; non-significant effect — dashed lines; *p < .05; **p < .005; ***p < .001.

Annex 7. Figure S3. Serial mediation model of the relationship between Self-Reported Physical Activity and Academic Achievement through Cardiorespiratory Fitness, Perceived Physical Literacy and Self-Perceived Academic Achievement (model c2) (study 3)



Note. n=218; n=218; X: predictor; Y: outcome; M1: mediator 1; M2: mediator 2; M3: mediator 3; CI: confidence intervals; Significant effect — continuous lines; non-significant effect — dashed lines; *p < .05; **p < .005; ***p < .001.

Annex 8. Figure S4. Serial mediation model of the relationship between Moderate to Vigorous Physical Activity and Academic Achievement through Motor Competence, Perceived Physical Literacy and Self-Perceived Academic Achievement (model c3) (study 3)



Note. n=148; n=218; X: predictor; Y: outcome; M1: mediator 1; M2: mediator 2; M3: mediator 3; CI: confidence intervals; Significant effect — continuous lines; non-significant effect — dashed lines; *p < .05; **p < .005; ***p < .001.