Regulación cognitiva en el aprendizaje basado en el movimiento: estrategias de comprensión como predictores de la comprensión multimodal en el ámbito físico.

Cognitive Regulation in Movement-Based Learning: Comprehension Strategies as Predictors of Multimodal Understanding in Physical Education

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Abstract

Introduction: Contemporary Physical Education (PE) emphasizes cognitively engaging movement and embodied learning. However, the integration of cognitive regulation within movement-based and multimodal learning contexts remains limited, particularly in elementary education where students must process written, audio, and audiovisual information simultaneously.

Objective: This study examines students' multimodal comprehension in PE contexts and analyzes comprehension strategies (planning, monitoring, evaluation) as cognitive predictors in movement-based learning environments.

Methodology: A mixed-methods explanatory sequential design was conducted with 56 fifth-grade students. Quantitative data were collected using Likert-scale questionnaires and multimodal comprehension tests embedded in movement-based activities, while qualitative data were obtained from open-ended responses. Data were analyzed using descriptive statistics, Pearson correlation, and thematic analysis.

Results: Students showed lower comprehension in written texts compared to audio and audiovisual formats. Planning was the most consistent predictor (r = 0.412–0.539), while monitoring and evaluation showed modality-specific effects.

Conclusions: Movement-based learning in PE enhances cognitive regulation and multimodal understanding, supporting integrated cognitive–physical development.

Keywords

Cognitive Regulation; Movement-Based Learning; Physical Education; Multimodal Learning; Metacognitive Strategies.

Resumen

Introducción: La educación física contemporánea enfatiza el movimiento cognitivo y el aprendizaje corporal. Sin embargo, la integración de la regulación cognitiva en contextos de aprendizaje multimodal y basados en el movimiento sigue siendo limitada, especialmente en la educación primaria, donde los estudiantes deben procesar información escrita, auditiva y audiovisual simultáneamente.

Objetivo: Este estudio examina la comprensión multimodal de los estudiantes en contextos de educación física y analiza las estrategias de comprensión (planificación, monitoreo y evaluación) como predictores cognitivos en entornos de aprendizaje basados en el movimiento.

Metodología: Se realizó un diseño secuencial explicativo de métodos mixtos con 56 estudiantes de quinto grado. Los datos cuantitativos se recopilaron mediante cuestionarios con escala Likert y pruebas de comprensión multimodal integradas en actividades basadas en el movimiento, mientras que los datos cualitativos se obtuvieron a partir de respuestas abiertas. Los datos se analizaron mediante estadística descriptiva, correlación de Pearson y análisis temático.

Resultados: Los estudiantes mostraron menor comprensión de textos escritos en comparación con los formatos de audio y audiovisuales. La planificación fue el predictor más consistente (r = 0,412–0,539), mientras que el seguimiento y la evaluación mostraron efectos específicos de cada modalidad.

Conclusiones: El aprendizaje basado en el movimiento en educación física mejora la regulación cognitiva y la comprensión multimodal, lo que favorece el desarrollo cognitivo-físico integrado.

Palabras clave

Regulación cognitiva; Aprendizaje basado en el movimiento; Educación física; Aprendizaje multimodal; Estrategias metacognitivas.

Introduction

Contemporary Physical Education (PE) is undergoing a significant paradigm shift from a traditional emphasis on motor skills and physical fitness toward a more holistic educational domain that integrates cognitive, social, emotional, and embodied dimensions of learning (Etkin, 2024). Recent advances in sport pedagogy emphasize that PE should not merely produce physically competent individuals, but also cultivate reflective participation, collaborative interaction, problem-solving abilities, and meaningful learning experiences through movement-based activities (Usher, Edwards & De Meyrick, 2015). Within this perspective, movement is not viewed as an isolated physical act or as a tool that merely supports cognitive outcomes; rather, movement constitutes an integral part of how learners experience, interpret, and construct knowledge through bodily engagement with their environment (Wang et al., 2019).

This transformation is particularly relevant in the context of 21st-century learning, where students are increasingly required to process information presented in multiple formats, including written, audio, and audiovisual texts (Keane, Keane & Blicblau, 2016). Such multimodal learning environments require learners to coordinate attention, interpretation, and meaning-making processes across different forms of representation (Sharma & Giannakos, 2020). The concept of multimodal (multiteks) comprehension reflects this complexity, as learners must integrate information, generate inferences, and adapt their understanding according to the characteristics of each modality (Cromley, Kunze & Dane, 2021). In movement-based learning contexts, these comprehension processes occur simultaneously with bodily interaction and physical participation, creating dynamic relationships between perception, action, reflection, and understanding.

From a theoretical perspective, this study is grounded in three complementary frameworks. First, embodied cognition theory posits that cognitive processes are deeply rooted in bodily interaction with the environment, suggesting that understanding develops through sensorimotor experience and active engagement rather than through purely abstract mental processing (Faella, Digennaro, & Iannaccone, 2025). Second, Self-Determination Theory (SDT) highlights that meaningful learning engagement emerges when learners experience autonomy, competence, and relatedness, all of which can be facilitated through participatory and movement-oriented learning experiences in PE contexts (Gray et al., 2018). Third, metacognitive regulation theory emphasizes the importance of planning, monitoring, and evaluation in enabling learners to regulate and optimize their comprehension processes across learning situations (Pintrich, 2002).

Previous studies have consistently demonstrated that physical activity and movement-based learning contribute positively to cognitive engagement, attention, motivation, and learning processes (Faella, Digennaro & Iannaccone, 2025). Similarly, research on multimodal learning has shown that learners' comprehension may vary depending on the characteristics of written, audio, and audiovisual materials (Albarra & Songkram, 2026; Albán, Monar & Sanga, 2025). However, existing literature has predominantly examined these areas separately. Studies on comprehension strategies are often situated within sedentary classroom or literacy contexts, whereas movement-based research in PE has more commonly emphasized participation, motivation, or physical outcomes rather than multimodal cognitive regulation processes. Consequently, limited attention has been given to how planning, monitoring, and evaluation strategies function within embodied and movement-based multimodal learning environments in Physical Education settings.

Empirical evidence suggests that students frequently demonstrate different levels of comprehension depending on text modality (Dickens & Meisinger, 2016). Audio and audiovisual formats may facilitate understanding through dual-channel processing and contextual support, whereas written texts often require more deliberate regulation and reflective processing (Chang, Tseng & Tseng, 2011). Nevertheless, the extent to which comprehension regulation strategies predict multimodal understanding within movement-based learning contexts remains insufficiently explored. In addition, differences in students' metacognitive awareness may influence how effectively they regulate comprehension while simultaneously engaging in physical activity and multimodal interaction.

Addressing these gaps, the present study proposes a movement-based cognitive regulation model in which comprehension strategies function as predictors of multimodal understanding within Physical Education contexts. Rather than positioning PE merely as a supportive medium for external cognitive outcomes, this study conceptualizes PE as an embodied learning environment where movement,

cognition, social interaction, and multimodal meaning-making interact dynamically during the learning process.

Therefore, this study aims to: (1) examine students' multimodal comprehension across different text modalities within movement-based PE activities, and (2) analyze the role of planning, monitoring, and evaluation strategies as cognitive predictors of multimodal understanding. By integrating metacognitive regulation with embodied and movement-based pedagogy, this study contributes to the growing interdisciplinary discourse on Physical Education as a holistic learning environment that supports meaningful cognitive, physical, and participatory development in contemporary education.

Method

Research Design

This study employed a mixed-methods approach using an explanatory sequential design to examine the role of comprehension strategies as cognitive predictors of multimodal understanding in movement-based Physical Education (PE) contexts (Orimaye, 2025). In this design, quantitative data were collected and analyzed in the first phase to identify statistical patterns and relationships among comprehension strategies and multimodal understanding. Subsequently, qualitative data were collected to explain, elaborate, and provide deeper interpretation of the quantitative findings. This design was selected because it enables the integration of numerical trends with students' lived experiences and cognitive regulation processes during movement-based learning activities (Heikkilä & Lonka, 2006).

The mixed-methods approach was considered appropriate because the study not only aimed to identify correlations between variables but also to understand how students applied planning, monitoring, and evaluation strategies while engaging in multimodal and physically active learning tasks. Therefore, the qualitative phase functioned as an explanatory component to strengthen the interpretation of the quantitative results and provide a more comprehensive understanding of movement-based cognitive regulation in PE contexts.

Participants

The participants consisted of 56 fifth-grade students (aged 10–11 years) from a public elementary school. A total sampling technique was applied, including all students in the selected class to ensure comprehensive representation of the learning context. For the qualitative phase, purposive sampling was used to select students representing low, medium, and high levels of multimodal comprehension based on quantitative test results. This selection allowed the researchers to explore variations in students' cognitive regulation strategies across different comprehension profiles.

Table 1. Participant Characteristics

Variable	Category	n	Percentage (%)
Gender	Male	27	48.2
	Female	29	51.8
Age	10 years	31	55.4
	11 years	25	44.6

Instruments

All constructs were measured using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), except for the multimodal comprehension test. Prior to data collection, the instruments were reviewed by experts in Physical Education and educational psychology to ensure content validity and conceptual appropriateness.

The Comprehension Strategy Questionnaire measured three dimensions of metacognitive regulation: planning, monitoring, and evaluation. Planning referred to students' preparation and goal-setting before engaging with multimodal materials; monitoring referred to students' awareness and control during comprehension processes; and evaluation referred to reflective processes after task completion. Sample items included statements such as "I plan how to understand the text before starting" and "I check whether I understand the material during the activity."

The Multimodal Comprehension Test assessed students' understanding across written, audio, and audiovisual formats through scenario-based questions integrated into movement-based PE activities. Students were required to process information while participating in physical tasks, thereby reflecting authentic embodied learning situations.

The Open-ended Questionnaire was designed to explore students' subjective experiences and strategy use during movement-based learning. Questions encouraged students to explain how they understood information, responded to difficulties, and reflected on their learning processes during physical activities.

Table 2. Instruments Overview

Instrument	Construct	Example Item	Reliability (α)
Comprehension Strategy Questionnaire	Planning, Monitoring, Evaluation	"I plan how to understand the text before starting"	0.88
Multimodal Comprehension Test	Written, Audio, Audiovisual comprehension	Scenario-based questions across modalities	0.86
Open-ended Questionnaire	Strategy use (qualitative)	"How do you understand the material during activities?"	—

Procedure

Data collection was conducted during regular PE classes to maintain ecological validity and preserve the natural learning environment. Prior to data collection, ethical approval was obtained from the institutional ethics committee. Permission was also granted by the school principal and Physical Education teachers. Because the participants were minors, written informed consent was obtained from parents or legal guardians, while verbal assent was obtained from the students before participation. Students were informed that participation was voluntary, that they could withdraw at any time without consequences, and that all responses would remain confidential and anonymous. To protect participants' privacy, all data were coded using pseudonyms and used exclusively for research purposes.
The learning activities were designed using a movement-based learning approach in which students engaged in physical activities while simultaneously processing multimodal information presented through written, audio, and audiovisual materials.
Each learning session consisted of three stages. First, students participated in a warm-up and instructional orientation session (10–15 minutes), during which teachers explained learning objectives, task procedures, and multimodal materials. During this phase, students were encouraged to activate prior knowledge and apply planning strategies before engaging in the activities.
Second, students completed movement-based learning tasks (40–50 minutes). These tasks involved physical movement integrated with multimodal comprehension activities, such as listening to audio instructions while performing coordinated movement patterns, interpreting audiovisual demonstrations during collaborative activities, and responding to written prompts embedded within physical tasks. The activities were designed to encourage active engagement, embodied interaction, and cognitive regulation throughout the learning process.
Third, students participated in reflection and discussion sessions (15–20 minutes). During this phase, students discussed difficulties encountered during the activities, explained the strategies they used to understand the materials, and reflected on how movement influenced their comprehension. Teachers facilitated reflective questioning to promote monitoring and evaluation processes.
At the end of the sessions, students completed the questionnaires and multimodal comprehension tests. Data collection lasted approximately two weeks.

Data Analysis

Quantitative data were analyzed using SPSS, including descriptive statistics, normality testing, and Pearson correlation analysis to examine relationships between comprehension strategies and multimodal understanding across text modalities.
Qualitative data obtained from open-ended responses were analyzed using thematic analysis. The analysis began with open coding to identify meaningful statements related to students' strategy use during movement-based learning activities. Similar codes were then grouped into broader categories representing patterns of planning, monitoring, and evaluation processes. Through iterative comparison, themes were developed to explain differences in students' multimodal comprehension and cognitive regulation experiences.

To strengthen the rigor of interpretation, cross-case comparisons were conducted among students with low, medium, and high comprehension levels. Finally, the qualitative findings were integrated with the quantitative results to explain statistical relationships and provide a more comprehensive understanding of how comprehension strategies function within movement-based multimodal learning environments.

Ethical Clearance

This research has been approved by the Research Ethics Committee, Community Service, and Publication Ethics Committee of PGRI Palembang University. Prior to data collection, formal permission was obtained from the school administration. Written informed consent was also obtained from parents or guardians because the participants were minors. Students were informed that participation was voluntary, and all responses were kept confidential and used solely for research purposes. Participants were also assured that they could withdraw from the study at any time without academic consequences.

Results

Psychometric Properties

Prior to hypothesis testing, the validity and reliability of the instruments were examined to ensure measurement accuracy and construct consistency. Confirmatory Factor Analysis (CFA) supported the three-factor structure of comprehension strategies consisting of planning, monitoring, and evaluation, with acceptable model fit indices (CFI = .95; TLI = .94; RMSEA = .052; SRMR = .041). These values indicate that the proposed measurement model adequately represented the observed data and supported the conceptual distinction among the three metacognitive dimensions.

All constructs demonstrated strong internal consistency:

1. Planning (α = .88)
2. Monitoring (α = .87)
3. Evaluation (α = .86)
4. Multimodal comprehension test (α = .86)

All reliability coefficients exceeded the recommended threshold (.80), indicating high reliability and satisfactory consistency among the instrument items.

Descriptive Statistics

Table 1. Descriptive Statistics of Main Variables

Variable	Mean	SD	Category
Planning	3.72	0.54	High
Monitoring	3.45	0.61	Moderate
Evaluation	3.38	0.58	Moderate
Multimodal Comprehension	3.18	0.69	Moderate

The descriptive results indicate that planning strategies were used more frequently than monitoring and evaluation strategies. This finding suggests that students tended to prepare cognitively before engaging in movement-based learning tasks but were less consistent in monitoring and evaluating their comprehension during and after the activities. The moderate level of overall multimodal comprehension indicates that students were able to process information across modalities, although variations emerged depending on the format of the learning materials.

Multimodal Comprehension Across Text Modes

Table 2. Distribution of Comprehension Levels

Text Mode	Low (%)	Medium (%)	High (%)
Written	58.93	30.36	10.71
Audio	17.90	46.43	35.67
Audiovisual	10.70	44.60	44.60

Students demonstrated the lowest comprehension in written texts, whereas audio and audiovisual formats showed substantially higher levels of understanding. More than half of the students were categorized in the low comprehension group for written texts, while audiovisual materials produced the highest proportion of students in the high comprehension category.

These findings indicate that multimodal and movement-supported learning environments may facilitate comprehension by reducing cognitive burden and increasing engagement. Audio and audiovisual inputs appeared to support students' understanding through dynamic and contextually rich representations, particularly when integrated with physical activities during PE sessions.

Correlation Analysis

Table 3. Pearson Correlation between Strategies and Comprehension

Strategy	Written	Audio	Audiovisual
Planning	0.412*	0.539**	0.467**
Monitoring	0.182 (ns)	0.544**	0.374*
Evaluation	0.535**	0.095 (ns)	0.298*

*Note: *p < .05, *$p < .01$, *ns = not significant*

The correlation analysis revealed modality-specific relationships between comprehension strategies and multimodal understanding. Planning emerged as the most consistent predictor across all modalities, with the strongest association found in audio comprehension (r = 0.539). This suggests that students who actively prepared and organized their understanding before engaging in learning tasks demonstrated better comprehension performance across text formats.

Monitoring demonstrated significant relationships with audio and audiovisual comprehension but not with written texts. This finding indicates that monitoring processes may become more important in dynamic learning situations requiring continuous attention and real-time adjustment. In contrast, evaluation showed the strongest relationship with written comprehension (r = 0.535), suggesting that reflective and review-oriented processes are particularly relevant when students process static textual information.

Interpretation of Effect Sizes

The magnitude of the relationships indicates meaningful practical significance:

1. Planning → Audio comprehension (r = 0.539) reflects a moderate-to-strong effect.
2. Evaluation → Written comprehension (r = 0.535) indicates a substantial cognitive effect.
3. Monitoring → Audio comprehension (r = 0.544) also demonstrates a strong regulatory role.

These effect sizes suggest that comprehension strategies function not merely as complementary learning supports but as substantial cognitive regulators within multimodal and movement-based learning environments. The findings further indicate that different metacognitive processes may become more prominent depending on the modality characteristics and cognitive demands of the task.

Qualitative Findings

Qualitative data from open-ended questionnaires were analyzed using thematic analysis. The coding process began with open coding to identify recurring statements related to students' strategy use during movement-based learning activities. Similar codes were grouped into categories and subsequently organized into broader themes representing patterns of metacognitive regulation.

Three major themes emerged from the analysis:

1. Structured Metacognitive Use (High-achieving students)

Students in this category consistently demonstrated planning, monitoring, and evaluation processes before, during, and after learning activities. Initial codes included "preparing before tasks," "checking understanding during movement," and "reflecting after activities." These codes were categorized into systematic regulation behaviors. Students frequently reported preparing strategies before engaging in activities and adjusting their understanding while interacting with multimodal materials.

2. Partial Strategy Use (Medium-achieving students)

Students applied comprehension strategies inconsistently and often only when difficulties emerged. Codes such as "sometimes reviewing instructions" and "asking for clarification when confused" were categorized as situational regulation behaviors. These students demonstrated awareness of comprehension strategies but lacked consistency in applying them throughout the learning process.

3. Reactive Strategy Use (Low-achieving students)

Students showed minimal planning and limited reflective processes. Codes included "following instructions directly" and "depending on peers during activities." These responses reflected reactive rather than proactive regulation patterns. Students tended to rely on external support and demonstrated limited self-monitoring during movement-based tasks.

Integration of Quantitative and Qualitative Findings

The integration of quantitative and qualitative findings demonstrates strong convergence between statistical patterns and students' reported learning experiences. Quantitatively, planning emerged as the strongest and most consistent predictor across modalities. Qualitatively, this finding was supported by evidence that high-performing students systematically engaged in pre-task preparation, goal setting, and comprehension planning before participating in movement-based activities.

Similarly, the modality-specific effects of monitoring and evaluation were clarified through qualitative findings. Students reported that audio and audiovisual tasks required continuous attention and immediate adjustment, explaining the stronger role of monitoring in dynamic modalities. Conversely, written tasks encouraged students to revisit and reconsider information, supporting the stronger role of evaluation in written comprehension.

Overall, the integrated findings suggest that movement-based multimodal learning environments shape not only students' comprehension outcomes but also the ways they regulate cognitive processes during learning.

Movement-Based Learning Engagement

Observational data indicated high student engagement during movement-based learning activities, with active participation estimated at approximately 85–90% of session time. Students remained physically engaged for an average of 40–50 minutes per session while simultaneously processing multimodal information.

The observations further showed that movement-based activities promoted collaborative interaction, sustained attention, and active participation during comprehension tasks. Students appeared more responsive and motivated when multimodal materials were integrated with physical movement, suggesting that embodied learning conditions may support both cognitive engagement and learning participation.

Discussion

The present study examined comprehension strategies as cognitive predictors of multimodal understanding within movement-based Physical Education (PE) contexts (Son, 2025; Putro et al., 2025). In this study, multimodal understanding refers to students' ability to comprehend, integrate, and

interpret information presented through written, audio, and audiovisual formats during movement-based learning activities. The findings demonstrate that students' comprehension varies across modalities, with written texts showing lower performance compared to audio and audiovisual formats (Rogowsky, Calhoun & Tallal, 2016). More importantly, planning emerged as the most consistent predictor across all modalities, while monitoring and evaluation exhibited modality-specific effects (Singh et al., 2024). These results provide empirical support for a movement-based cognitive regulation model, in which cognitive processes are dynamically shaped by both modality and embodied learning conditions (Zou et al., 2025).

Theoretical Contribution to Sport Pedagogy

These findings are consistent with previous research indicating that multimodal learning environments enhance comprehension through dual-channel processing and increased cognitive engagement (Chang, Tseng & Tseng, 2011). In the present study, multimodal learning refers to learning processes involving the simultaneous use of multiple representational formats, including written, auditory, and audiovisual information integrated within physical activities. However, unlike prior studies that primarily examined comprehension strategies in sedentary classroom settings, this study demonstrates that such strategies operate differently within movement-based learning environments (Aloizou et al., 2025).

From the perspective of embodied cognition theory, the results suggest that physical activity supports cognitive processing by linking sensorimotor experience with information encoding (Kiefer & Trumpp, 2012). Embodied learning in this context refers to learning processes in which cognition emerges through bodily movement, interaction, and physical engagement with learning tasks rather than through passive information reception alone. The higher comprehension observed in audio and audiovisual formats may reflect the alignment between dynamic input and movement-based engagement, which facilitates attention and memory integration (De Koning, Zhang, & Sepp, 2025). This extends existing literature by showing that cognitive regulation is not context-neutral but influenced by the physical conditions of learning (Zhao et al., 2025).

Furthermore, the findings align with Self-Determination Theory (SDT), as movement-based tasks in PE may enhance students' sense of autonomy, competence, and engagement, thereby supporting more effective use of cognitive strategies (Mondaca-Fernandez, 2019). In this study, cognitive regulation refers to students' ability to plan, monitor, and evaluate their comprehension processes while interacting with multimodal learning materials during physical activity. Students who actively engage in structured movement appear more capable of applying planning strategies consistently, suggesting that physical engagement may strengthen metacognitive readiness (Su, 2026).

The differential effects of monitoring and evaluation across modalities also provide important theoretical insights (Aston, et al., 2022). Monitoring was more effective in audio and audiovisual contexts, where real-time processing is required, whereas evaluation was more relevant in written and audiovisual contexts, where reflection and review are possible (Crocco et al., 2016). This supports the argument that metacognitive strategies are modality-sensitive and context-dependent, rather than universally applied across learning environments (Xiao, Wang & Jiang, 2026).

Importantly, the effect sizes indicate that planning demonstrates moderate-to-strong predictive power, while monitoring and evaluation show moderate effects (Suzuki & Kormos, 2025). These effect sizes suggest that comprehension strategies function not merely as complementary tools but as substantial cognitive regulators in movement-based multimodal learning (De Koning, Zhang & Sepp, 2025).

Comparison with Previous Studies

This finding is consistent with previous studies showing that planning is a strong predictor of comprehension in traditional literacy contexts. However, unlike prior research, this study demonstrates that planning remains robust even in physically active learning environments, highlighting its foundational role in cognitive regulation. In contrast, earlier studies often report uniform effects of monitoring and evaluation across text types. The present findings challenge this assumption by showing that their effectiveness varies depending on modality. This discrepancy may be explained by the embodied nature of the learning context, where physical engagement alters cognitive demands and processing dynamics. Thus, this study extends current literature by positioning comprehension strategies not only as predictors of learning outcomes but as adaptive mechanisms that interact with both modality and movement.

Implications for Physical Education and Sport Pedagogy

These findings reinforce the pedagogical role of Physical Education as a platform for cognitive as well as physical development. In this study, movement-based learning refers to instructional activities that integrate bodily movement with cognitive and multimodal learning tasks. Movement-based learning in PE is not limited to motor skill acquisition but can facilitate higher-order cognitive processes, including comprehension, regulation, and reflection. First, the results suggest that integrating multimodal learning within PE can enhance students' cognitive engagement. Audio and audiovisual materials, when combined with movement-based tasks, appear particularly effective in supporting understanding. Second, the consistent role of planning highlights the importance of explicit strategy instruction in PE. Teachers should guide students to activate prior knowledge, set learning goals, and prepare cognitively before engaging in tasks.

Third, the modality-specific nature of monitoring and evaluation suggests that instructional design should be adapted to the characteristics of the learning material. For example:

1. Audio-based tasks should emphasize real-time monitoring.
2. Written tasks should include structured reflection and evaluation.

Overall, these findings support the view that Physical Education can function as an embodied learning environment that integrates cognitive regulation with physical activity, aligning with contemporary sport pedagogy frameworks.

Limitations

Several limitations should be acknowledged. First, the study employed a cross-sectional design, which limits causal inference. While significant relationships were identified, the directionality of effects cannot be fully established. Second, the use of self-report questionnaires may introduce response bias, particularly in measuring students' use of comprehension strategies. Future studies should incorporate observational or performance-based measures of metacognition. Third, the study was conducted within a single elementary school in Indonesia, which may limit the generalizability of the findings to other cultural and educational contexts. Differences in curriculum, teaching practices, and student characteristics may influence the applicability of the results.

Future Research Directions

Future research should employ longitudinal or experimental designs to examine causal relationships between movement-based learning and cognitive regulation. Additionally, incorporating objective measures such as behavioral tracking or neurocognitive indicators may provide deeper insights into how physical activity influences cognitive processes. Further studies are also needed to explore how different types of movement (e.g., high-intensity vs. moderate activity) interact with multimodal learning and metacognitive strategies.

Conclusions

This study contributes to the growing discourse on contemporary Physical Education (PE) by positioning movement-based learning as an embodied educational process in which cognitive, physical, and multimodal experiences interact dynamically. Rather than viewing cognition as separate from bodily activity, the study supports the perspective that understanding is constructed through active engagement, movement participation, reflection, and interaction with multimodal learning materials. In this sense, comprehension strategies such as planning, monitoring, and evaluation should be understood as integrated regulatory processes that emerge within embodied learning experiences.

The proposed movement-based cognitive regulation model extends current discussions in sport pedagogy and multimodal learning by demonstrating that Physical Education can function as a meaningful context for both cognitive and physical development. The study reinforces the interdisciplinary role of PE, not merely as a subject focused on motor performance, but as a pedagogical space that supports metacognitive engagement, reflective learning, and multimodal meaning-making.

From a pedagogical perspective, the findings suggest that movement-based instructional designs integrating written, audio, and audiovisual materials may strengthen students' engagement and support more adaptive learning processes. The study also highlights the importance of explicitly facilitating planning, monitoring, and reflective activities during PE instruction so that students can regulate their understanding while actively participating in movement tasks.

Overall, this study provides theoretical and practical implications for embodied learning and contemporary sport pedagogy. Future research is encouraged to employ longitudinal and experimental approaches to further examine the dynamic relationship between movement, multimodal comprehension, and cognitive regulation across diverse educational and cultural contexts.

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