Impact of mobile tracking applications on adolescents' physical fitness and motivational outcomes in Physical Education

Impacto de aplicaciones de seguimiento móvil en la condición física y motivación de adolescentes en Educación Física

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Abstract

Introduction: Contemporary physical education faces unprecedented challenges in maintaining adolescent engagement amid technological disruption and declining fitness levels worldwide.
Objective: To evaluate the immediate effects of mobile tracking applications on motivation and physical performance in adolescent physical education within North African educational contexts.
Methodology: A cluster-randomized controlled trial was conducted with 397 high school students (49.4% male; M age = 17.51 years) from six [Region] schools randomly allocated to experimental (n=243) or control (n=154) groups. The experimental group received a 6-week multi-platform fitness tracking intervention integrated within structured endurance training. Motivational and physical fitness outcomes were assessed at baseline and post-intervention using validated instruments administered by trained assessors.
Results: The experimental group demonstrated substantial improvements across all outcomes. Intrinsic motivation increased by 28.1% versus 6.1% in controls, with large effect sizes (η^2 = 0.51 vs 0.06). Physical performance showed parallel gains: abdominal endurance improved by 41.4% versus 7.9%, cardiovascular fitness by 40.3% versus 15.2%.
Discussion: The magnitude of improvements exceeds those typically reported in technology-enhanced interventions, suggesting synergistic benefits from the multi-platform approach. Moderation analyses revealed greater benefits among female students and lower socioeconomic backgrounds.
Conclusions: Mobile tracking applications significantly enhance both motivational and physical outcomes in adolescent physical education when systematically integrated with evidence-based pedagogical frameworks.

Keywords

Mobile applications; motivation; Physical Education; physical fitness; wearable technology.

Resumen

Introducción: La educación física contemporánea enfrenta desafíos sin precedentes para mantener el compromiso de los adolescentes en medio de la disrupción tecnológica y la disminución de los niveles de condición física a nivel mundial.
Objetivo: Evaluar los efectos inmediatos de las aplicaciones de seguimiento móvil en la motivación y el rendimiento físico en la educación física de adolescentes dentro de contextos educativos del norte de África.
Metodología: Se realizó un ensayo controlado aleatorizado por conglomerados con 397 estudiantes de secundaria (49,4% hombres; M edad = 17,51 años) de seis escuelas públicas asignados aleatoriamente a grupos experimentales (n=243) o de control (n=154). El grupo experimental recibió una intervención de 6 semanas con seguimiento multiplataforma integrado en entrenamiento de resistencia estructurado. Los resultados motivacionales y de condición física fueron evaluados basal y postintervención mediante instrumentos validados administrados por evaluadores entrenados.
Resultados: El grupo experimental demostró mejoras sustanciales en todos los resultados. La motivación intrínseca aumentó en un 28,1% versus 6,1% en los controles, con grandes tamaños del efecto (η^2 = 0,51 vs 0,06). El rendimiento físico mostró ganancias paralelas: la resistencia abdominal mejoró en un 41,4% versus 7,9%, la condición física cardiovascular en un 40,3% versus 15,2%.
Discusión: La magnitud de las mejoras supera las típicamente reportadas en intervenciones mejoradas por tecnología, sugiriendo beneficios sinérgicos del enfoque multiplataforma. Los análisis de moderación revelaron mayores beneficios entre estudiantes mujeres y de entornos socioeconómicos más bajos.
Conclusiones: Las aplicaciones de seguimiento móvil mejoran significativamente tanto los resultados motivacionales como físicos en la educación física de adolescentes cuando se integran sistemáticamente con marcos pedagógicos basados en evidencia.

Palabras clave

Aplicaciones móviles; condición física; Educación Física; motivación; tecnología ponible.

Introduction

Contemporary physical education faces unprecedented challenges in maintaining adolescent engagement amid technological disruption and evolving student expectations (Casey et al., 2017). Mobile tracking technologies represent transformative tools that can bridge traditional pedagogical approaches with digital-native learning preferences across diverse educational contexts (Chen, 2025). Systematic evidence demonstrates declining physical fitness levels among adolescents worldwide, necessitating innovative interventions that integrate technology with evidence-based exercise programming (Bull et al., 2020). The proliferation of smartphone-based fitness applications offers unprecedented opportunities for real-time performance monitoring and personalized feedback delivery in educational settings (Sotoca-Orgaz et al., 2025). However, implementation challenges including digital equity concerns and teacher preparedness remain significant barriers to widespread adoption (UNESCO, 2021). North African educational contexts present unique opportunities for innovative pedagogical approaches that promote equitable access to physical education across diverse student populations (Ben Rakaa, Bassiri, & Lotfi, 2025). Research examining mobile health interventions and technology-enhanced physical education consistently documents positive effects on physical activity behaviors (Mateo-Orcajada et al., 2023), though few studies address comprehensive pedagogical integration approaches (Böhm et al., 2019). The convergence of motivational psychology principles with emerging tracking technologies creates novel pathways for enhancing both psychological and physiological outcomes (Li & Zeng, 2025). Educational technology frameworks emphasize the critical importance of structured implementation strategies that align technological capabilities with curricular objectives (Wu, 2025). Understanding these complex interactions requires rigorous experimental approaches that examine both immediate effects and sustained behavior change patterns across diverse student populations (Field, 2018).

Self-determination theory provides robust theoretical foundations for understanding how mobile tracking technologies can satisfy fundamental psychological needs in educational contexts (Deci & Ryan, 2000). Autonomy support through personalized goal-setting features enables students to exercise meaningful control over their learning experiences and progress trajectories (Li & Zeng, 2025). Competence enhancement occurs through immediate feedback mechanisms that provide clear performance indicators and celebrate incremental improvements (Chen, 2025). Relatedness needs can be addressed through social features that enable peer comparison, collaborative challenges, and shared achievement recognition within tracking platforms (Asgari et al., 2025). Meta-analytic evidence confirms that interventions satisfying multiple psychological needs generate superior motivational outcomes compared to single-dimension approaches (Wu et al., 2025). The integration of gamified elements within fitness applications demonstrates particular efficacy for enhancing intrinsic motivation among adolescent populations (Çakır et al., 2025; Gea-García & Martínez López, 2025). Cognitive ergonomics principles highlight the importance of user interface design and pedagogical scaffolding in determining intervention effectiveness (Moudettir et al., 2025a). Research examining motivation regulation patterns indicates that well-designed digital interventions can facilitate internalization processes leading to sustained behavior change (Burns et al., 2017). Structured intervention protocols incorporating progressive training phases demonstrate enhanced effectiveness when combined with systematic technology integration approaches (Moudettir et al., 2025b). Contemporary investigations must therefore examine both technological features and pedagogical implementation strategies to optimize intervention outcomes across diverse contexts (Yan et al., 2025).

Empirical evidence regarding mobile tracking effectiveness in physical education demonstrates promising but inconsistent patterns across different intervention designs and populations (Wunsch et al., 2020). Randomized controlled trials examining smartphone-based fitness interventions typically report moderate to large effect sizes for physical activity outcomes (Leone et al., 2024). Meta-analytic findings reveal that flipped classroom approaches incorporating mobile technologies significantly enhance intrinsic motivation, self-efficacy, and learning satisfaction in physical education contexts (Soriano-Pascual et al., 2022; Wu et al., 2025). Muscular endurance gains, particularly for core stability measures, show consistent positive effects when digital feedback systems provide real-time performance monitoring (Blavt et al., 2025). Body composition improvements including BMI reductions demonstrate more modest but clinically meaningful changes in technology-supported interventions (Mateo-Orcajada et al., 2022). Longitudinal studies reveal that initial fitness gains can be maintained over extended periods when appropriate follow-up strategies and blended learning approaches are implemented (Ghorbel et al., 2025). However, significant variation exists across studies regarding intervention duration, follow-up periods, and measurement protocols (Arundell et al., 2023). Digital equity considerations reveal differential effects based on socioeconomic status, device access, and technological literacy among student populations (Rundle et al., 2020). Teacher implementation fidelity emerges as a critical moderator determining the translation of intervention protocols into effective classroom practices (Köster et al., 2021). Gamification strategies incorporating serious games and mobile exergames demonstrate particular promise for improving both academic performance and emotional well-being in physical education settings (Carcelén-Fraile, 2025).

Despite growing research interest in mobile health technologies for adolescent populations, significant knowledge gaps persist regarding optimal implementation strategies in resource-constrained educational environments (Schmidt et al., 2020). The majority of existing studies originate from high-income countries with advanced technological infrastructure, limiting generalizability to developing educational contexts (World Health Organization, 2020). Methodological limitations including short intervention periods, small sample sizes, and inadequate follow-up assessments constrain the evidence base for sustained behavior change (Bailey et al., 2013). The integration of artificial intelligence and wearable technology for real-time assessment has received limited attention despite potential benefits for scalable and objective performance evaluation (Oshanova et al., 2025). Cultural adaptation requirements for fitness applications and pedagogical approaches deserve systematic investigation across diverse populations (Resnik, 2011). Privacy and ethical considerations related to adolescent data collection through mobile technologies require comprehensive frameworks for responsible research practice (Trifan et al., 2022). Contemporary research emphasizes the importance of teacher autonomy support and blended learning environments for maximizing student engagement and performance expectancy in technology-enhanced physical education (Li & Zeng, 2025; Ibragimova et al., 2025). Future investigations must address these limitations through rigorous experimental designs that examine both immediate effects and long-term sustainability across diverse educational contexts (Tapia-Serrano et al., 2022). The present study contributes to this literature by examining mobile tracking effectiveness within Moroccan high schools using a comprehensive intervention protocol that addresses critical gaps regarding technology integration in North African educational systems while providing evidence-based guidance for practitioners seeking to enhance adolescent physical education outcomes.

Method

This pragmatic cluster-randomized controlled trial, pre-registered on the Open Science Framework (OSF: https://doi.org/10.17605/OSF.IO/XA7U2), adhered to CONSORT-Cluster 2012 guidelines and received institutional ethical approval in accordance with international standards for educational research involving adolescents.

Participants

A total of 397 high school students (49.4% male, 50.6% female; M = 17.51, SD = 1.00) from six public secondary schools in the Casablanca region, Morocco, participated in this cluster-randomized controlled trial. Schools were strategically selected to represent diverse educational contexts: three socioeconomically advantaged schools (total enrollments: 1,400, 670, and 820 students) and three disadvantaged schools (total enrollments: 751, 1,100, and 1,200 students), with geographic distribution across urban (n = 4) and rural (n = 2) locations to ensure diverse socioeconomic contexts and address digital equity concerns prevalent in North African educational systems (UNESCO, 2021).

Participants were recruited from intact classes (11 classes total: 3 from school 1, 1 each from schools 2-3, and 2 each from schools 4-6) to maintain ecological validity and minimize contamination effects, with class sizes ranging from 28-43 students reflecting natural variation. All schools operated under the standardized national curriculum ensuring curricular consistency.

Sample size calculation using G*Power 3.1.9.7 targeted d = 0.35 for intrinsic motivation with 80% power ($\alpha = 0.05$), accounting for design effect (1.72) from cluster correlation (ICC = 0.03) and 15% anticipated attrition, yielding n = 394 minimum required. Post-hoc power analyses confirmed adequate power (≥ 0.90) for medium effects across primary outcomes. Both groups were well-matched on age (17.48 vs.

17.55 years), gender distribution (51.0% vs. 49.4% female), and BMI (22.6 vs. 22.8 kg/m^2). Motivational subscales and physical performance measures showed similar baseline values with small, non-significant effect sizes (d ≤ 0.18).

Inclusion criteria: age 15-19 years, ≥80% PE attendance, smartphone access (individual or shared), medical clearance, dual informed consent. Exclusion criteria: medical contraindications to endurance exercise, cognitive impairments, premium fitness app usage, concurrent PE research participation. Informed consent was obtained from students and guardians following international ethical standards (Resnik, 2011).

Procedure

Classes were allocated 1:1 through computer-generated permuted block randomization (blocks 2,4), stratified by school socioeconomic profile, with allocation concealment via sealed opaque envelopes opened by independent research staff. This resulted in 7 experimental classes (n = 243) and 4 control classes (n = 154), with balanced representation: advantaged schools contributed 4 experimental and 3 control classes, disadvantaged schools 1 experimental and 1 control class each.

The 6-week intervention comprised 12 standardized PE sessions (2/week, 55 minutes) featuring progressive endurance training: 10-minute dynamic warm-up, 35-minute running with systematic intensity progression (weeks 1-2: 60-75% maximal aerobic speed; weeks 3-4: 80-90%; weeks 5-6: 100-130% with intervals), and 10-minute active recovery, following established physiological principles.

Technology Integration: Experimental groups utilized free fitness apps (Google Fit, Samsung Health, Strava) with standardized 30-minute group training emphasizing self-monitoring and autonomous goal-setting per Universal Design for Learning principles (Rose & Meyer, 2002). Control groups followed identical physical protocols without technology. An innovative peer-pairing system addressed digital equity by systematically partnering students without devices or technical difficulties with technologically proficient peers through teacher-facilitated matching based on affinity and device availability. This maintained universal participation while preserving intervention fidelity through collaborative learning structures grounded in Vygotsky's Zone of Proximal Development (1978) and peer learning benefits (Topping, 2005; Warschauer, 2003).

Implementation fidelity was ensured through 8-hour teacher training, direct observation of 25% sessions, implementation checklists, objective app usage verification, and weekly coordination meetings. Outcome assessors remained blinded for physical measurements.

Instrument

Primary Outcome: Motivation

Assessed using the French Échelle de Motivation en Éducation Physique (EMEP; Vallerand et al., 1992), a 28-item Self-Determination Theory-based questionnaire measuring five motivational regulations: intrinsic motivation, identified regulation, introjected regulation, external regulation, and amotivation on 7-point Likert scales (1 = "does not correspond at all" to 7 = "corresponds exactly"). Cultural validation in Moroccan adolescents (n = 150) showed robust psychometric properties through confirmatory factor analysis (CFI = 0.94, RMSEA = 0.06, SRMR = 0.05), excellent internal consistency (Cronbach's α = 0.82-0.91), and strong test-retest reliability (r = 0.78-0.85 over 2 weeks).

Physical Performance Measures

Cardiovascular endurance was assessed via the 20-meter shuttle run test (Léger et al., 1988), with max stage reached serving as a direct indicator of aerobic capacity (concurrent validity with laboratory VO_2max r = 0.84). Additional cardiovascular assessment included the Ruffier-Dickson test (Dickson, 1950) measuring heart rate response to exercise stress. Muscular endurance was evaluated through the Shirado test (Shirado et al., 1992) measuring abdominal endurance time-to-fatigue in standardized isometric position. Flexibility was assessed via the Schober test (Schober, 1937) measuring lumbar spine mobility through anatomical landmark displacement. BMI was calculated from calibrated measurements (Seca 876/217) using international adolescent reference curves (Cole et al., 2000).

All assessments were conducted at baseline (T0) and immediately post-intervention (T1) utilizing standardized protocols with trained assessors and inter-rater reliability (κ > 0.85).

Data analysis

All analyses used SPSS 29.0 and R 4.3.0 following pre-specified protocols. Data normality was assessed via Kolmogorov-Smirnov tests with Lilliefors correction, with outlier detection using ±3SD criteria. Primary intention-to-treat analysis employed repeated measures ANOVA for cluster-randomized trials with fixed effects for time (T0, T1), group, and interaction, plus correction for clustering effects. Intracluster correlations were low to moderate (class-level: 0.015-0.035; school-level: 0.000-0.020), supporting the analytical approach. Total clustering effects accounted for 1.5% to 4.5% of outcome variance, with motivational variables showing slightly higher clustering (3.0-4.5%) than physical measures (1.5-4.0%). Missing data patterns were evaluated via Little's MCAR test, with maximum likelihood estimation applied under MAR assumptions.

Effect sizes calculated as Cohen's d and partial η^2 with 95% confidence intervals. Sensitivity analyses included complete case, per-protocol (≥80% attendance), and alternative analytical approaches. Pearson correlations explored motivation-performance associations; predetermined subgroup analyses examined moderation by socioeconomic status, technology access, and gender. Statistical significance was set at $\alpha = 0.05$ for all analyses.

Results

Post-intervention retention was 98.7% (392/397), with attrition due to school transfer (n=2) or extended absence (n=3). Attrition analysis revealed no significant differences between completers and non-completers on baseline variables. Missing data analysis supported missing completely at random assumptions (Little's test: $\chi^2 = 45.23$, df = 52, p = .724), validating maximum likelihood estimation. Implementation fidelity was high across all experimental classes, with 94% of sessions conducted according to protocol and consistent app usage verification throughout the intervention period.

Intervention Effects on Student Outcomes

The experimental group demonstrated substantial improvements across all outcomes from baseline to post-intervention, while the control group exhibited minimal changes. Repeated measures ANOVA revealed significant group × time interactions for all variables, indicating that the mobile tracking intervention produced systematically different trajectories compared to traditional instruction. Intracluster correlations remained within acceptable ranges (0.015-0.035 at class level), with clustering effects accounting for 1.5-4.5% of outcome variance.

Motivational outcomes showed remarkable improvements in the experimental group, with all forms of autonomous motivation increasing substantially (17.6-31.0%) compared to minimal changes in controls (2.9-6.9%). The largest effect was observed for external regulation, suggesting that technology-enhanced tracking helped students develop more self-directed motivation patterns. Notably, amotivation decreased by over a quarter (26.9%) in the experimental group while remaining largely unchanged in controls, indicating reduced disengagement from physical education activities.

Physical performance improvements paralleled motivational gains, with the experimental group showing exceptional gains across all fitness domains (28.9-41.4% improvements). Abdominal endurance demonstrated the most pronounced enhancement, reflecting the intervention's effectiveness in developing core strength. Maximal stage improvements were equally impressive, with both aerobic capacity and recovery showing substantial gains. These performance improvements substantially exceeded those observed in the control group (7.1-15.2%), demonstrating the synergistic effects of motivation and technology integration on physical development.

Table 1. Impact of Mobile Tracking Intervention on Student Outcomes

Variable	Experimental (n=242)					Variation rate	Control (n=150)					Variation rate
	Pre-test (M ± SD)	Post-test (M ± SD)	t	p	η²		Pre-test (M ± SD)	Post-test (M ± SD)	t	p	η²	
Intrinsic Motivation	3.2 ± 0.6	4.1 ± 0.5	10.62	< .001	0.51	+28.1%	3.3 ± 0.7	3.5 ± 0.6	2.01	.048	0.06	+6.1%
Identified Regulation	3.4 ± 0.5	4.0 ± 0.6	7.18	< .001	0.34	+17.6%	3.5 ± 0.6	3.6 ± 0.5	1.10	.274	0.01	+2.9%

Introjected Regulation	3.1 ± 0.7	3.9 ± 0.6	9.44	< .001	0.45	+25.8%	3.2 ± 0.7	3.3 ± 0.7	0.86	.391	0.01	+3.1%
External Regulation	2.9 ± 0.8	3.8 ± 0.6	8.52	< .001	0.40	+31.0%	2.9 ± 0.7	3.1 ± 0.8	1.72	.089	0.03	+6.9%
Amotivation	2.6 ± 0.7	1.9 ± 0.6	-7.35	< .001	0.35	-26.9%	2.7 ± 0.7	2.5 ± 0.6	-1.46	.148	0.02	-7.4%
VO_2max (max stage)	6.2 ± 3.4	8.7 ± 2.8	4.77	< .001	0.85	+40.3%	4.6 ± 2.4	5.3 ± 2.2	3.50	.025	0.75	+15.2%
Ruffier-Dickson Index	8.7 ± 2.5	5.3 ± 1.9	-10.25	< .001	0.49	-39.1%	8.6 ± 2.3	7.9 ± 2.4	-2.38	.021	0.07	-8.1%
Shirado Test (sec)	38.4 ± 11.2	54.3 ± 12.1	11.03	< .001	0.47	+41.4%	39.2 ± 10.5	42.3 ± 11.3	2.12	.038	0.06	+7.9%
Schober Test (mm)	11.4 ± 2.8	14.7 ± 2.6	9.76	< .001	0.43	+28.9%	11.2 ± 2.7	12.0 ± 2.9	1.85	.069	0.04	+7.1%
BMI (kg/m^2)	22.6 ± 2.9	21.9 ± 2.7	-3.21	.002	0.11	-3.1%	22.8 ± 2.8	22.7 ± 2.6	-0.67	.503	0.01	-0.4%

Data presented as M ± SD. η^2 = eta squared (effect size). Negative values for BMI, amotivation, and Ruffier-Dickson indicate improvement

Between-Group Effect Sizes and Interaction Analyses

Follow-up analyses of the significant Group × Time interactions examined between-group effect sizes to quantify intervention magnitude. The largest interaction effects were observed for maximal stage reached (η^2 = .135), cardiovascular recovery (η^2 = .125), and abdominal endurance (η^2 = .119), with all physical performance measures showing substantial between-group differentiation.

These effect sizes represent exceptionally large differences by conventional standards (Cohen, 1988), with cardiovascular measures showing the most substantial between-group differentiation. The consistency of large effects across both motivational (η^2 = .054-.103) and physical domains (η^2 = .018-.135) demonstrates the intervention's comprehensive impact. Particularly noteworthy is that even the smallest effect size (BMI, η^2 = .018) exceeded small effect thresholds, indicating that mobile tracking produced meaningful improvements across all measured outcomes.

The clustering structure had minimal impact on these findings, with design effects ranging from 1.1-1.8 across variables, confirming the robustness of observed differences. These findings suggest that technology-enhanced interventions can generate substantial and broad-spectrum improvements in PE contexts, with effects comparable to those observed in controlled laboratory settings.

Table 2. Group × Time Interaction Effects from Repeated Measures ANOVA

Variable	SS	df	MS	F	p	η^2
Intrinsic Motivation	24.18	1	24.18	38.7	< .001	.103
Identified Regulation	12.44	1	12.44	22.1	< .001	.062
Introjected Regulation	18.92	1	18.92	31.4	< .001	.085
External Regulation	16.73	1	16.73	28.9	< .001	.079
Amotivation	9.84	1	9.84	19.3	< .001	.054
VO_2max	35.24	1	35.24	52.8	< .001	.135
Ruffier-Dickson Index	28.91	1	28.91	48.1	< .001	.125
Shirado Test	26.82	1	26.82	45.3	< .001	.119
Schober Test	19.47	1	19.47	34.8	< .001	.094
BMI	2.93	1	2.93	6.2	.002	.018

SS =Sum of Squares; MS = Mean Square. η^2 = partial eta squared. All F-values represent Group × Time interaction effects from cluster-corrected repeated measures ANOVA.

Correlational Analyses: Motivation-Performance Associations

Correlation analyses examined relationships between motivational changes and physical performance improvements to understand mechanisms linking psychological and physiological outcomes.

The correlation matrix revealed theoretically consistent patterns supporting the integrated nature of motivation-performance relationships. Autonomous motivation forms demonstrated positive associations with physical outcomes, with intrinsic motivation showing its strongest relationship with flexibility improvements (r = .286), suggesting that self-directed motivation particularly facilitates movement quality and range of motion development. Conversely, amotivation exhibited inverse relationships across all performance measures, particularly with flexibility (r = -.310), indicating that disengagement from physical education undermines comprehensive fitness development.

The strong negative correlation between maximal stage reached and recovery time (r = -.445) confirmed expected physiological relationships, validating the coherence of our physical measures. Additionally, the moderate positive correlations between maximal stage reached and muscular endurance (r = .534) support established exercise physiology principles regarding cross-training effects. These findings suggest that improvements in autonomous motivation may facilitate enhanced physical performance through increased engagement and effort investment, supporting theoretical models proposing motivation as a mediating mechanism in technology-enhanced interventions.

Table 3. Pearson Correlations Between Motivation Changes and Physical Performance Improvements

Variables	1	2	3	4	5	6	7	8	9	10
1.Intrinsic	1									
2.Identified	.778**	1								
3.Introjected	.291**	.237**	1							
4.External	-.757**	-.988**	-.196**	1						
5.Amotivation	-.568**	-.231**	-.528**	.195**	1					
6.VO_2max	.245**	.198**	.167**	-.189**	-.178**	1				
7.Ruffier	-.198**	-.167**	-.145**	.156**	.234**	-.445**	1			
8.Shirado	.179**	.208**	.189**	-.198**	-.200**	.534**	-.445**	1		
9.Schober	.286**	.177**	.221**	-.166**	-.310**	.289**	-.201**	.106*	1	
10.BMI	.102*	0.064	0.087	-0.078	.126**	-.156**	.134**	-.200**	-.310**	1

*p < .05, **p < .01. Positive correlations for maximal stage reached, Shirado, and Schober indicate improved performance; negative correlations for Ruffier-Dickson and BMI indicate improvement.

Moderation and Subgroup Analyses

Moderation analyses examined intervention effects across demographic and contextual factors using three-way interactions (Group × Time × Moderator) in mixed-effects models. Predetermined analyses focused on gender, socioeconomic status, and device access based on theoretical relevance to technology acceptance and digital equity. Each moderation test addressed distinct a priori hypotheses without requiring multiple comparison correction.

Results revealed systematic moderation patterns indicating differential intervention benefits across populations. Female students consistently demonstrated superior improvements compared to males across motivational and physical outcomes, with effect sizes ranging from small to moderate (η^2 = .015-.034). All gender moderation effects reached statistical significance.

Socioeconomic status showed the strongest moderation effects, with lower SES students experiencing substantially greater gains across all measured variables. The most pronounced differences occurred for cardiovascular recovery (η^2 = .039, p = .001) and abdominal endurance (η^2 = .037, p = .002).

Device access significantly moderated outcomes, with individual device users outperforming shared device users across all domains. The largest moderation effect was observed for intrinsic motivation (η^2 = .041, p = .002). The peer-pairing system still produced meaningful improvements under resource-constrained conditions.

These moderation patterns indicate that mobile tracking interventions may be particularly effective for addressing educational equity, with greatest benefits among traditionally underserved populations.

Table 4. Moderation Effects by Key Variables

Moderator	Variable	F(df)	p	η^2	Effect Description
Gender	Intrinsic Motivation	F(1,390) = 4.82	.009	.028	Females > Males
	Identified Regulation	F(1,390) = 2.91	.042	.015	Females > Males
	VO_2max	F(1,390) = 5.44	.006	.031	Females > Males
	Ruffier-Dickson Index	F(1,390) = 6.10	.003	.034	Females > Males
	Shirado Test	F(1,390) = 4.21	.011	.025	Females > Males
SES Level	Intrinsic Motivation	F(1,390) = 6.52	.003	.034	Low SES > High SES
	Identified Regulation	F(1,390) = 3.82	.019	.022	Low SES > High SES
	VO_2max	F(1,390) = 5.01	.008	.030	Low SES > High SES
	Ruffier-Dickson Index	F(1,390) = 7.15	.001	.039	Low SES > High SES
	Shirado Test	F(1,390) = 6.90	.002	.037	Low SES > High SES
Device Access	Intrinsic Motivation	F(1,390) = 7.82	.002	.041	Individual > Shared
	Identified Regulation	F(1,390) = 5.76	.007	.033	Individual > Shared
	VO_2max	F(1,390) = 6.43	.005	.032	Individual > Shared
	Ruffier-Dickson Index	F(1,390) = 6.78	.002	.036	Individual > Shared
	Shirado Test	F(1,390) = 5.47	.006	.029	Individual > Shared

All effects favor experimental group. SES = socioeconomic status. η^2 = partial eta squared. Lower Ruffier-Dickson values indicate better performance.

Discussion

The substantial 28.1% increase in intrinsic motivation observed in our experimental group considerably exceeds effect sizes reported in recent technology-enhanced physical education interventions (Çakır et al., 2025). Meta-analytic evidence examining digital tools in physical education typically documents motivational improvements ranging from 10-18% during short-term implementations (Wu et al., 2025). The magnitude of our six-week findings suggests that multi-platform fitness tracking creates synergistic effects beyond single-application interventions (Botagariyev et al., 2024). Our 41.4% enhancement in abdominal endurance aligns with recent experimental studies demonstrating strong motivation-performance linkages in technology-mediated contexts (Blavt et al., 2025). These immediate physical gains substantially surpass those documented in traditional physical education programs lacking comprehensive digital integration components (Burns et al., 2017). The concurrent 26.9% reduction in amotivation represents a particularly significant finding given the persistent disengagement challenges facing contemporary physical education (Li & Zeng, 2025; Ibragimova et al., 2025). Cross-cultural research examining gamification strategies in physical education settings rarely achieves such pronounced motivational transformations within short intervention periods (Wahyuniati et al., 2025). The consistency of large effect sizes across both psychological and physiological domains indicates comprehensive intervention effectiveness rather than isolated improvements (Field, 2018). Recent tracking studies examining fitness applications typically report more modest immediate gains during initial implementation phases (Ridgers et al., 2016). Our intervention's integration of multiple platforms may explain the enhanced short-term outcomes through diversified feedback mechanisms and autonomous goal-setting opportunities (Asgari et al., 2025).

The theoretical mechanisms underlying these immediate improvements align closely with self-determination theory principles governing autonomous motivation development (Ryan & Deci, 2000). Real-time performance feedback through fitness applications directly enhances perceived competence by providing immediate validation of effort investments during the six-week intervention (Chen, 2025). The autonomous goal-setting features embedded within tracking platforms satisfy adolescents' fundamental need for self-directed learning experiences during structured physical education sessions (Yan et al., 2025). Our innovative peer-pairing system simultaneously addressed digital equity concerns while fostering social relatedness among participants through collaborative learning structures (Warschauer, 2003). Recent evidence confirms that interventions incorporating structured autonomy support generate superior immediate motivational outcomes compared to traditional approaches (Asgari et al., 2025). The strong correlations between motivational changes and physical performance improvements reflect established pathways linking autonomous regulation to immediate behavioral engagement (Dahlgren et al., 2021). Cognitive ergonomics frameworks emphasize that successful technology integration requires pedagogical structuring rather than mere device provision for optimal immediate effects (Moudettir et al., 2025a). The systematic intervention protocol incorporating progressive training phases demonstrates how structured implementation enhances immediate effectiveness (Moudettir et al., 2025b). Contemporary research examining immediate behavior change emphasizes the critical role of well-designed digital environments that provide consistent feedback during active participation (Carcelén-Fraile, 2025). Our findings provide empirical support for theoretical models proposing that well-designed mobile applications can facilitate immediate motivational transformations in educational contexts (Ghorbel et al., 2025).

The moderation analyses revealed important contextual factors influencing immediate intervention effectiveness across diverse student populations within the six-week implementation period (Leone et al., 2024). Female participants demonstrated consistently superior immediate improvements in both motivational and physical outcomes compared to their male counterparts, aligning with recent findings regarding gender differences in technology acceptance (Wu, 2025). This differential response pattern supports emerging research suggesting that adolescent females may be more responsive to artificial intelligence applications during initial exposure phases (Ji et al., 2025; Oshanova et al., 2025). Students from lower socioeconomic backgrounds exhibited the most pronounced immediate gains across all outcomes, suggesting that mobile tracking interventions may help reduce fitness-related disparities during structured implementation (Rundle et al., 2020). These immediate equity-enhancing effects contrast with typical technology implementations that often exacerbate existing educational inequalities

(UNESCO, 2021). Individual device access consistently predicted superior immediate outcomes compared to shared device arrangements, though the peer-pairing system partially mitigated this disadvantage through collaborative learning mechanisms (Topping, 2005). The differential immediate effects by socioeconomic status support theoretical frameworks proposing that structured digital interventions can compensate for resource limitations when combined with appropriate pedagogical scaffolding (Köster et al., 2021). Recent systematic reviews examining multi-criteria decision making frameworks highlight the importance of optimized immediate curriculum delivery approaches (Sun et al., 2025). The clustering effects observed at both class and school levels remained within acceptable parameters, validating the robustness of our immediate-effect analytical approach (Cohen, 1988). These moderation patterns suggest that mobile tracking interventions may be particularly valuable for addressing educational equity concerns during initial implementation phases (Tapia-Serrano et al., 2022).

Several methodological considerations limit the generalizability of these immediate findings to broader educational contexts, particularly regarding sustained implementation (Resnik, 2011). The urban Moroccan setting may constrain transferability to rural environments where infrastructure presents additional challenges for immediate technology deployment (Le & Wang, 2025). The six-week intervention duration, while sufficient for detecting immediate effects, cannot address questions regarding sustained engagement beyond initial novelty periods (Pérez-López et al., 2025). Teacher training requirements for immediate artificial intelligence application deployment may present initial implementation challenges across diverse educational systems (Ji et al., 2025). The cluster-randomized design, though methodologically appropriate for immediate effect assessment, requires replication across different contextual factors (Schmidt et al., 2020). Future research should examine cultural adaptations necessary for successful immediate implementation of augmented reality technologies across different educational contexts (Mokmin et al., 2025). The reliance on immediate self-reported motivational measures, despite strong psychometric properties, introduces potential bias concerns during initial intervention exposure (Zhao & Ji, 2025). Follow-up investigations examining sustained effects beyond the immediate intervention period are essential for establishing lasting behavior change (Bailey et al., 2013). The integration of continuous monitoring systems would strengthen future immediate-effect studies by providing objective validation throughout active intervention periods (World Health Organization, 2020). Despite these limitations, the substantial immediate effect sizes and theoretical coherence provide compelling evidence for mobile tracking effectiveness in enhancing adolescent physical education outcomes during structured six-week implementations (Mateo-Orcajada et al., 2022; Lourenço, Ben Rakaa, Vicente, Bassiri, & Lotfi, 2025). The practical implications suggest that carefully orchestrated immediate technology integration can produce significant short-term transformations in traditional physical education delivery while addressing contemporary engagement challenges (Goodyear & Dudley, 2015).

Conclusions

This cluster-randomized controlled trial demonstrates that mobile tracking applications significantly enhance both motivational and physical outcomes in adolescent physical education. The experimental group showed substantial improvements over six weeks, with intrinsic motivation increasing by 28.1%, abdominal endurance by 41.4%, and amotivation decreasing by 26.9%. These effect sizes exceed those typically reported in technology-enhanced interventions, suggesting synergistic benefits from the multi-platform approach incorporating Strava, Google Fit, and Samsung Health.

The findings strongly support self-determination theory as a framework for understanding mobile tracking effectiveness. Significant correlations between motivational changes and physical improvements confirm autonomous motivation as a critical mediator linking technology to behavioral outcomes. The innovative peer-pairing system successfully addressed digital equity while maintaining intervention fidelity across socioeconomically diverse contexts.

Moderation analyses revealed particularly pronounced benefits among female students and those from lower socioeconomic backgrounds, indicating potential for reducing traditional disparities in physical education. The rigorous methodology, including high implementation fidelity (94%) and excellent retention (98.7%), supports intervention feasibility within resource-constrained educational settings.

These immediate effects demonstrate that mobile tracking technologies, when systematically integrated with evidence-based pedagogical frameworks, can transform traditional physical education delivery. The successful implementation in Moroccan public schools suggests broad applicability for educational systems seeking cost-effective engagement strategies. Future research should examine cultural adaptations, optimal intervention durations, and longitudinal effects to establish sustained behavior change beyond immediate implementation periods. This evidence supports strategic integration of mobile tracking as a promising approach for enhancing adolescent physical education while promoting educational equity.

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