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HARMONIZING THE SPEED-POWER PROFILE: A LONGITUDINAL ANALYSIS OF SPECIALIZED CHEERLEADING TRAINING VS. SCHOOL PE IN PRE-PUBERTAL GIRLS

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Abstract: This 9-month longitudinal study investigated the specific effects of specialized Cheerleading training on the Speed-Power profile of pre-pubertal girls aged 8–10 years. Sixty participants (n=20/group) were assigned to a Cheerleading Training Group (CG), a General Sports Group (GSG), or a Control Group (CON). Performance in 10 m Sprint (10m Speed), Standing Long Jump (SLJ), and Medicine Ball Throw (MBT) was assessed at four time points (T1–T4) using the OptoJump system. Differences in developmental trajectory were examined using 3 × 4 Mixed-Model ANOVA, and effect sizes were calculated using Cohen's d. Additionally, a One-Way ANOVA analyzed training effects on the Asynchronism Index (ΔMBT/ΔSLJ). All groups improved over time; however, the Group × Time interaction was highly significant for 10m Speed, SLJ, and MBT ($p \leq .001$), indicating that training specificity determined the rate of development. The CG demonstrated the steepest trajectory of improvement, yielding very large differential gains compared to the CON (10m Speed: $d = –2.03$; SLJ: $d = 1.97$; MBT: $d = 1.74$). Differences between CG and GSG were also notable,

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particularly for upper-body power (MBT: d = 0.92), highlighting the specificity of the Cheerleading stimulus. Developmental balance was significantly influenced by training type, as shown by the Asynchronism Index (p = .043), with the CG presenting a more proportional evolution of upper and lower kinetic chains. A moderate positive correlation between SLJ and MBT at T4 (r = .411; p = .001) further emphasized systemic adaptations in power development. In conclusion, specialized Cheerleading training is significantly more effective than general sports participation or PE alone in accelerating and harmonizing the Speed-Power trajectory in pre-pubertal girls. The findings support integrating structured power-focused methods into developmental training programs to ensure optimal, balanced neuromuscular evolution during early childhood.

Key words: speed and power, plyometrics, pre-pubertal motor development, motor performance,

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INTRODUCTION

Background and Significance of Pre-pubertal Motor Development

The pre-pubertal period (typically encompassing 8-10 years of age) is widely recognized in sports science literature as a critical window of opportunity for optimizing neuromuscular efficiency and motor skill acquisition (Ratel et al., 2004; Lloyd & Oliver, 2012). During this phase, the central nervous system exhibits heightened plasticity, facilitating rapid motor learning and efficient adaptation to specific speed-strength stimuli (Faigenbaum et al., 2015).

Optimal development of the Speed-Power profile defined as the capacity to generate maximal force in minimal time is fundamental for subsequent athletic performance and long-term musculoskeletal health (Stone et al., 2006). Key components of this profile include Linear Speed (10m Sprint), reflecting acceleration capability; Lower Body Explosive Power (Standing Long Jump - SLJ), indicating horizontal force production; and Upper Body Explosive Power (Medicine Ball Throw - MBT), which measures trunk-to-arm kinetic chain efficiency.

The Research Gap and Problem Statement

Despite the recognized importance of this developmental window, the capacity of standard school-based Physical Education (PE) programs to induce significant adaptive gains in speed and power parameters remains debated (Lesinski et al., 2016). Studies have suggested that while general motor skills improve naturally due to biological maturation (Malina, 2004), the intensity, frequency, and specificity of the stimulus provided by conventional PE are often insufficient to drive substantial gains compared to structured, specialized training (Dotan et al., 2020). Similar demands for early coordination and mobility development are observed in rhythmic gymnastics (Sabău et al., 2023)

This insufficiency can lead to asynchronous or unbalanced motor development. Specifically, upper-body power (MBT) in young female athletes is frequently underdeveloped, potentially creating 'weak links' in the kinetic chain compared to lower-body power (Harman, 2008). Previous research has largely focused on short-term interventions or has relied on post-intervention comparisons, failing to robustly analyze the longitudinal trajectory (i.e., the rate of change or slope) of improvement over an entire training macrocycle.

This lack of longitudinal data, specifically comparing a high-power, plyometric-intensive sport (such as Cheerleading) against general and control groups over a period sufficient to elicit long-term adaptations (9 months), represents a crucial gap in the understanding of motor development specificity.

Study Aims

Addressing this methodological gap, the present study sought to quantify the differential effects of a 9-month specialized training protocol on the dynamic development of the Speed-Power profile in pre-pubertal girls.

The specific aims of this research were:

To evaluate the Group × Time Interaction (longitudinal trajectory) in 10m Speed, Standing Long Jump (SLJ), and Medicine Ball Throw (MBT) between the three intervention groups (Cheerleading, General Sports, and Control) across four testing points (T1–T4).

To determine the magnitude of the differential training effect (Δ) between the specialized Cheerleading Group and the Control Group using Cohen's d (Cohen, 1988).

To analyze the influence of training specificity on the balance of motor development by quantifying the change in the Asynchronism Index (ΔMBT/ΔSLJ).

METHODOLOGY

Participants

The study sample comprised a total of 60 female subjects (age range: 8–10 years; mean age = 9.2 ±0.6 years) recruited from schools in the local area. Participants were voluntarily enrolled based on written informed consent provided by their legal guardians (table 1).

Subjects were divided into three independent groups, with n=20 per group, based on their participation in organized extracurricular sports activities:

Cheerleading Training Group (CG): Subjects who participated weekly in two standard school Physical Education (PE) lessons (2 x 50 minutes) and two sessions of specialized Cheerleading training (2 x 75 minutes), with a high content of plyometric and speed-strength exercises.

General Sports Group (GSG): Subjects who participated weekly in two PE lessons (2 x 50 minutes) and two sessions of general sports training (2 x 75 minutes), including activities such as handball, basketball, karate, or modern dance (mixed stimulus).

Control Group (CON): Subjects who participated exclusively in the two weekly school PE lessons (2 x 50 minutes), with no additional structured sports training.

Table 1. Anthropometric Characteristics of the Participants at Baseline

Variable	Cheerleading Group (n=20)	General Sports Group (n=20)	Control Group (n=20)	F-value	p-value
Age (years)	9.2±0.6	9.1±0.7	9.3±0.5	0.45	.641
Body Mass (kg)	29.50±6.93	27.70±5.14	28.50±10.59	0.26	.771
Body Height (m)	1.31±0.08	1.29±0.05	1.31±0.14	0.45	.638
BMI (kg/m2)	17.00±2.89	16.63±2.63	16.02±2.66	0.66	.518

Values are presented as Mean ± Standard Deviation. BMI = Body Mass Index. The p-values indicate no significant differences between groups at baseline ($p > .05$), confirming sample homogeneity.

Inclusion Criteria: Participation in the respective group activity for the entire duration of the study (9 months); no history of musculoskeletal injuries in the 6 months preceding T1. Exclusion Criteria: Any interruption of the training/PE protocol exceeding two consecutive weeks; failure to complete all four testing sessions.

Study Design

The research employed a 3 x 4 factorial longitudinal design (three intervention groups x four measurement time points), conducted over a period of nine months. This approach allowed for the analysis of the training specificity across time (table 2).

The four measurement points were: T1: Baseline measurement (Start of the study/academic year); T2: 3-month follow-up; T3: 6-month follow-up; T4: 9-month follow-up (Post-intervention).

Table 2. The 9-Month Vector-Specific Plyometric Training Protocol.

Mesocycle & Focus	***Specific Exercises (Examples)***	***Volume & Progression (Per Session)***
Odd Cycles (1, 3, 5) *Vertical Vector Focus* *(Stiffness & Vertical Power)*	1. Jump Rope: Double-leg pogo jumps, High-knee skips. 2. Hoop Jumps: Precision jumps inside gymnastic hoops (continuous). 3. Hurdle Hops (15cm): Continuous vertical bounding over mini-hurdles. 4. Ankle Hops: Focus on short ground contact time (GCT).	*Volume:* *Cycle 1: 2 sets x 8 reps/drill.* *Cycle 3: 3 sets x 10 reps/drill.* *Cycle 5: 3-4 sets x 12 reps (High Intensity).* *Duration: 10-12 min.* *Rest: 60-90s between sets.*
Even Cycles (2, 4, 6) *Horizontal Vector Focus* *(Acceleration & Distance)*	1. Frog Jumps: Deep squat to horizontal jump. 2. Standing Long Jump (SLJ): Focus on hip extension. 3. Single-Leg Bounds: "Step-hop" sequences for distance. 4. Bounds: Continuous forward jumping (left-right-left).	*Volume:* *Cycle 2: 2 sets x 6 reps (Technical focus).* *Cycle 4: 3 sets x 8 reps.* *Cycle 6: 3 sets x 10-12 reps (Max distance).* *Duration: 10-15 min.* *Rest: 90-120s (Higher neural demand).*

The intervention took place over a period of 9 months, divided into 6 distinct mesocycles, each lasting 6 weeks following standard periodization principles (Bompa & Haff, 2009). The specialized Cheerleading training program (CG) included a specific 10–15 minute plyometric module performed immediately after the standard warm-up, twice a week.

To ensure a comprehensive stimulation of the Speed-Power profile, the protocol employed a Vector-Specific Periodization strategy (Loturco et al., 2015), alternating between Vertical Force Vector dominance during odd-numbered mesocycles (targeting stiffness and vertical acceleration) and Horizontal Force Vector dominance during even-numbered mesocycles (targeting horizontal propulsion and acceleration mechanics). The intensity and volume were progressively increased throughout the macrocycle

Protocols and Measurement Tools

All motor tests were administered by the same certified research team, ensuring standardized procedures. Prior to each testing session, subjects performed a standardized, supervised warm-up.

Equipment

All time-based and displacement-based measurements were recorded using the OptoJump Next System (Microgate, Bolzano, Italy). This photoelectric cell system ensures high reliability and precision (±0.001 s resolution) for the assessment of speed and explosive power.

Performance Variables

Three key variables reflecting the Speed-Power profile were assessed:

10m Sprint (10m SPEED): Used to assess acceleration and horizontal explosive force. Subjects started from a standing position and the time (s) was recorded using the OptoJump system, positioned at 0 m and 10 m. The fastest of two attempts was recorded.

Standing Long Jump (SLJ): Used to assess lower-limb horizontal explosive power. The distance (cm) was measured from the take-off line to the nearest point of contact upon landing. The best of three attempts was recorded

Medicine Ball Throw (MBT - 1 kg): Used to assess upper-body explosive power. Subjects threw a 1 kg medicine ball from a seated position (overhead or chest pass method, standardized). The distance (cm) was measured. The best of three attempts was recorded.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics software (Version 28.0) and R (Version 4.2.0). Significance was set at an alpha level of $p \leq .05$.

Primary Analysis: Repeated Measures ANOVA

To evaluate the differential effects of training over time, a 3 × 4 Mixed-Model Analysis of Variance (ANOVA) with Repeated Measures was performed for each performance variable (10m Speed, SLJ, and MBT).

Between-Subject Factor: Group (CG, GSG, CON).

Within-Subject Factor: Time (T1, T2, T3, T4).

The primary outcome of interest was the Group × Time Interaction, which signifies that the trajectory of change is significantly different across the three groups.

Secondary and Post-Hoc Analyses

Sphericity and Post-Hoc: The assumption of sphericity was assessed using Mauchly's Test. If violated, the Greenhouse-Geisser correction was applied. Significant main effects were followed up with pairwise comparisons using the Bonferroni adjustment.

Effect Size (ES): The magnitude of effects was reported using Partial Eta Squared (ηp^2) for the RM ANOVA (small $\eta p^2 \geq .01$; medium $\eta p^2 \geq .06$; large $\eta p^2 \geq .14$) and Cohen's d for post-hoc pairwise comparisons (small d=0.2; medium d=0.5; large d=0.8).

Asynchronism Index: To quantify the balance of motor development, an index of change was calculated as the difference between post-intervention and baseline scores (Δ = T4 - T1) for the MBT/SLJ Ratio. A separate One-Way ANOVA was conducted on the ΔMBT / ΔSLJ ratio to determine if training specificity influenced the proportionality of power development.

Relationships between Variables: Pearson Product-Moment Correlation (r) was used to determine the linear association between the final scores (T4) of 10m Speed, SLJ, and MBT within the combined sample.

RESULTS

The total sample size analyzed was N=60 female subjects (n=20 per group: Cheerleading Group [CG], General Sports Group [GSG], and Control Group [CON]). Levene's test confirmed the equality of variances, and initial one-way ANOVA at baseline (T1) showed no statistically significant differences between the groups for any dependent variable ($p > .05$), ensuring sample homogeneity.

Descriptive Statistics and Overall Longitudinal Change

Table 3 presents the mean performance scores ($\bar{X}$) and standard deviations (SD) at baseline (T1), alongside the total change score (Δ = T4 - T1) over the 9-month intervention period.

Table 3. The 9-Month Vector-Specific Plyometric Training Protocol.

Variable	Group	T1 Mean ± SD	Δ Mean (T4 – T1)	Δ SD
10m Speed (s)	CG	2.91 ± 0.32	–0.44	0.28
	GSG	3.12 ± 0.32	–0.26	0.23
	CON	3.08 ± 0.38	–0.15	0.16
SLJ (cm)	CG	127.35 ± 11.23	+17.20	8.26
	GSG	116.70 ± 10.39	+13.50	12.06
	CON	114.70 ± 15.01	+10.25	9.53

MBT (cm)	CG	153.60 ± 35.53	+42.70	20.37
	GSG	130.65 ± 29.54	+20.60	27.28
	CON	114.70 ± 36.31	+14.95	12.00

For 10m Speed, a negative Δ indicates performance improvement (faster time)

Longitudinal Trajectory Analysis: 3 x 4 Repeated Measures ANOVA

The Mixed-Model ANOVA confirmed a significant main effect for Time for all three dependent variables ($p < .001$), indicating general performance improvement across the 9-month period.The analysis of the Group x Time Interaction was the primary focus, as it tests whether the rate of improvement (trajectory) differs significantly among the three intervention groups (table 4).

Table 4. Summary of Group x Time Interaction Effects for Performance Variables

Variable	F	p-value	Partial ηp²	Interpretation of Interaction
10m Speed	8.47	.001	.229	Highly Significant (Large Effect)
SLJ	25.40	<.001	.471	Highly Significant (Very Large Effect)
MBT	9.61	<.001	.252	Highly Significant (Large Effect)

A highly significant Group × Time interaction was observed for all three variables: 10m Speed ($F(2, 57) = 8.47$, $p = .001$, $\eta p^2 = .229$), SLJ ($F(2, 57) = 25.40$, $p < .001$, $\eta p^2 = .471$), and MBT ($F(2, 57) = 9.61$, $p < .001$, $\eta p^2 = .252$). These results robustly confirm that the specific Cheerleading training protocol resulted in a distinct and significantly steeper developmental trajectory compared to the other groups.

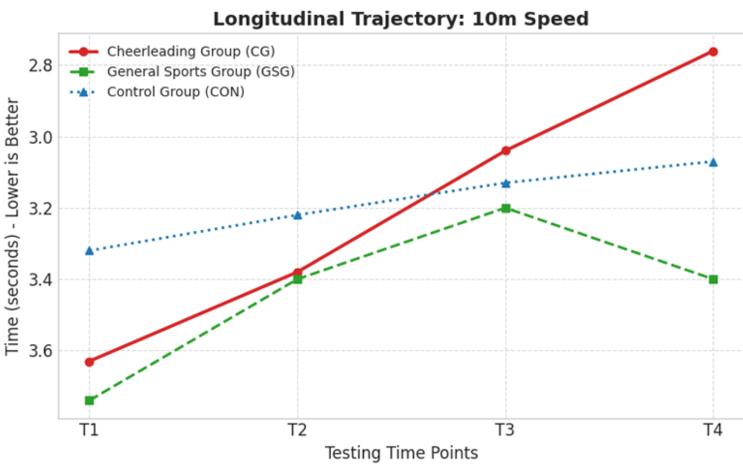

Figure 1. Longitudinal trajectory of 10m Speed performance across four time points (T1-T4). Note the steep downward slope (indicating improvement) for the Cheerleading Group (CG) compared to the relative plateau of the Control (CON) and General Sports (GSG) groups.

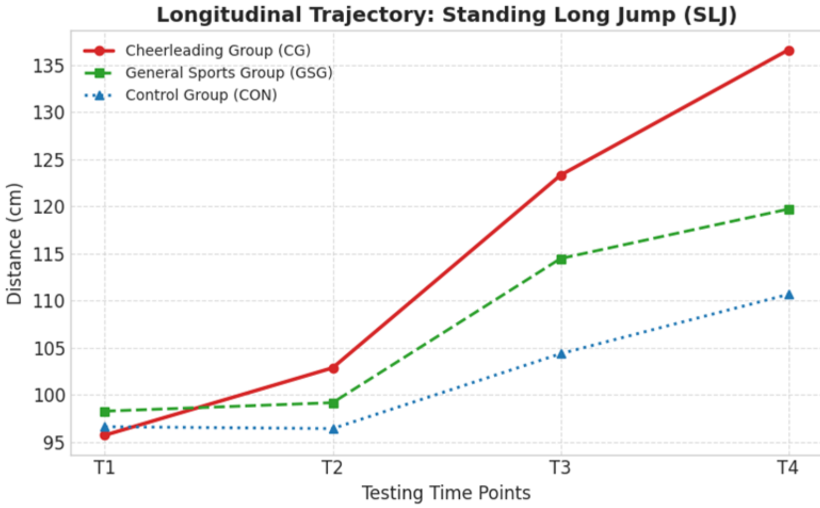

Figure 2. Longitudinal trajectory of Lower Body Power (Standing Long Jump). The divergence between the specialized training group and the control groups becomes clearly visible after the T2 mark (3 months)

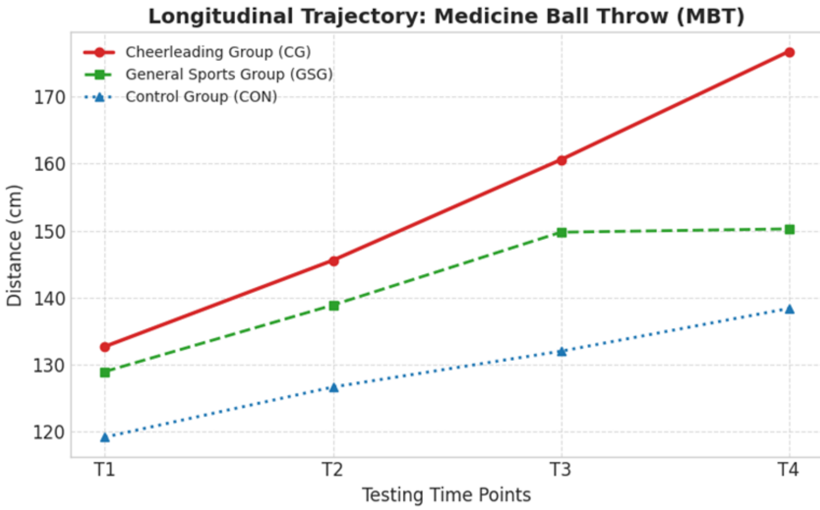

Figure 3. Longitudinal trajectory of Upper Body Power (Medicine Ball Throw). This figure illustrates the most pronounced specific training effect, with the CG showing a vastly superior rate of improvement compared to general physical education.

Post-Hoc Comparisons and Effect Size

While the comparison between CG and CON yielded Very Large Effect Sizes across all variables ($d > 1.70$), the comparison between CG and GSG revealed more nuanced differences. Specifically, for Upper Body Power (MBT), the specialized training proved significantly more effective than general sports training ($d = 0.92$, Large Effect), highlighting the specificity of the cheerleading stimulus. For 10m Speed, the CG also outperformed the GSG with a medium-to-large effect ($d = -0.70$). However, in Lower Body Power (SLJ), the difference between specialized and general training was less pronounced (d = 0.36), suggesting that general sports participation also provides a stimulus for leg power, albeit inferior to the specialized protocol. Finally, the GSG vs. CON comparisons showed generally Small to Medium effects (d = 0.27 - 0.55), confirming that while general activity is better than PE alone, it does not induce the same magnitude of adaptation as the specialized cheerleading program (table 5).

Table 5: Pairwise Comparisons of Differential Gain (Δ) and Effect Sizes (Cohen's d) across All Groupsable 4.

Variable	Contrast	Mean Diff (Δ)	Cohen's d	Effect Interpretation
10m Speed	CG vs. CON	-0.29 s	-2.03	Very Large
	CG vs. GSG	-0.18 s	-0.70	Medium to Large
	GSG vs. CON	-0.11 s	-0.55	Medium
SLJ	CG vs. CON	+6.95 cm	1.97	Very Large
	CG vs. GSG	+3.70 cm	0.36	Small to Medium
	GSG vs. CON	+3.25 cm	0.30	Small
MBT	CG vs. CON	+27.75 cm	1.74	Very Large
	CG vs. GSG	+22.10 cm	0.92	Large
	GSG vs. CON	+5.65 cm	0.27	Small

Asynchronism Index and Concurrent Correlation

Asynchronism Index A separate One-Way ANOVA on the total change of the MBT/SLJ Ratio (ΔMBT/ΔSLJ) was statistically significant, $F(2, 57) = 3.33$, $p = .043$, $\eta p^2 = .105$. This finding supports the hypothesis that the type of training significantly influences the balance of power development, with the Control Group exhibiting a trajectory associated with greater developmental imbalance.

Concurrent Correlation Pearson Product-Moment Correlation was used to assess the relationship between final scores (T4). A moderate, positive, and statistically significant correlation was observed between the Standing Long Jump (SLJ) and the Medicine Ball Throw (MBT), $r(58) = .411$, $p = .001$. This indicates that subjects who excelled in lower-body power also tended to exhibit higher levels of upper-body power, suggesting a generalizable effect of power development across the kinetic chain, particularly within the intervention groups.

DISCUSSION

The present longitudinal study aimed to evaluate the differential effects of a 9-month specialized Cheerleading training program versus standard physical education on the Speed-Power profile of pre-pubertal girls, focusing on the detection of the Group × Time interaction trajectory. The findings strongly support the central hypothesis, confirming that specific training induces a significantly superior and distinct developmental pathway in all three measured performance components.

Differential Trajectory and Training Specificity

The detection of a highly significant Group × Time interaction (Table 4) across 10m Speed ($p = .001$) and Medicine Ball Throw (MBT) ($p < .001$) is the most critical finding. This demonstrates that the specific rate of improvement (trajectory) was dictated by the intervention type, surpassing the gains expected from natural maturation (Malina, 2004). The large effect sizes associated with these interactions ($\eta p^2 \geq .229$) highlight the practical relevance of the specialized stimulus.

The pronounced gains in MBT (Δ = +42.70 cm) are particularly noteworthy. Given that Cheerleading requires intense upper-body speed-strength for partner stunts and movements, this result aligns perfectly with the Specificity of Training Principle (Haff & Nimphius, 2012). The post-hoc analysis revealed that the differential gain between the Cheerleading and Control groups was profound, evidenced by a Very Large Effect Size ($d = 1.74$) for ΔMBT (Table 5). This magnitude of change far exceeds the typical gains reported in generalized physical activity programs for this age group (Lesinski et al., 2016).

Similarly, the superior acceleration gains in the CG group (Cohen's $d = –2.03$) underscore the efficacy of incorporating plyometric-based jumps and high-velocity movements in pre-pubertal training, consistent with literature advocating for specialized speed-power work in the developmental stage (Ratel et al., 2004; Faigenbaum et al., 2015) and consistent with the specificity principle (Zatsiorsky & Kraemer, 2006)

Notably, the significant improvement in 10m Speed occurred despite the lack of specific sprint volume, highlighting a strong 'transfer of training' effect. The vector-specific plyometric protocol—targeting both vertical stiffness and horizontal propulsion—enhanced the neuromuscular power required for acceleration. For pre-pubertal girls, increasing explosive power through structured jumping is a highly time-efficient strategy to improve speed, even without extensive track-based sprinting. This supports the efficacy of plyometrics in dynamic youth sports (Ramirez-Campillo et al., 2015) and confirms the strong relationship between lower limb power and linear speed in young athletes (Huțanu et al., 2024)

Asynchronous Development and Kinetic Chain Balance

While the SLJ also showed a strong interaction effect ($\eta p^2 = .471$), the finding regarding the Asynchronism Index (ΔMBT/ΔSLJ ratio) offers a novel perspective. The statistically significant difference in the evolution of this ratio ($p = .043$) suggests that the type of training influences the balance of power development between the upper and lower kinetic chain segments.

In the absence of specific upper-body stimulus (Control Group), lower-body strength (driven by locomotion and general play) tends to advance disproportionately. The CG intervention, by coupling high-demand lower-body training with structured upper-body actions, appears to have guided development toward a more integrated and proportional power profile, supporting the concept of balanced strength development as a protective factor against injury (Harman, 2008). The correlation analysis further supports this link, showing a moderate concurrent relationship between upper and lower power at T4 ($r = .411$, $p = .001$), suggesting that power development, while specific, retains an element of systemic transfer (Kunz et al., 2020).

The results for SLJ are further clarified when considering the highly significant interaction effect. Although the SLJ test is a general measure of horizontal power, the magnitude of the effect ($\eta p^2 = .471$) suggests that the Cheerleading stimulus provided a substantially superior trajectory of improvement compared to the Control Group. This aligns with findings demonstrating the positive impact of plyometric loading on jumping ability in youth (Meylan & Malatesta, 2009).

Limitations and Future Directions

A key limitation of this work lies in the study design, specifically the non-randomized assignment of participants, a common constraint in school-based intervention research. While the analysis of Δ scores provides robust evidence of effect size (Cohen, 1988), future studies could incorporate mixed-effects regression models to further explore individual variability in maturation rates.

In conclusion, the longitudinal data, analyzed through an interaction-based statistical approach, provides compelling evidence that specialized training focused on speed and plyometric power is superior to standard physical education in establishing a robust and balanced Speed-Power profile in young female athletes

CONCLUSIONS

Based on the highly significant Group × Time interactions and the large effect sizes observed in the present longitudinal study, the following conclusions are drawn:

Specialized Training is Superior: Nine months of specialized Cheerleading training induced a significantly different and superior developmental trajectory in the Speed-Power profile (10m Speed, SLJ, and MBT) in pre-pubertal girls compared to standard Physical Education alone.

Specific Adaptations: The largest differential gains were observed in Medicine Ball Throw (ΔMBT, Cohen's d = 1.74), confirming that the specific plyometric and power-based demands of Cheerleading are highly effective in stimulating adaptations in upper-body speed-strength, a component often neglected in general youth training.

Balanced Development: The specialized training approach fostered a more integrated development of the kinetic chain, as evidenced by the statistically significant difference in the ΔMBT/ΔSLJ ratio, suggesting a more balanced power output between the upper and lower extremities.

Implications: The results advocate for the structured inclusion of high-velocity, specific power training methods, even at the pre-pubertal stage, to ensure optimal and asynchronous development of the Speed-Power profile for both long-term athletic development and general fitness.

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