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Original Article

The neuromuscular effects of including a third weekly stimulus in Physical Education students in Secondary School

Short title: Neuromuscular effects of weekly stimulus frequency

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Abstract

Insufficient neuromuscular stimuli in school-based Physical Education (PE) may hinder the development of strength and speed-related fitness in adolescents, and evidence supporting increased weekly training frequency in schools remains limited. This quasi-experimental study examined the effects of adding a third weekly neuromuscular training session to the standard PE curriculum. Twenty-eight secondary school students (≈ 17 years) were assigned to an Intervention Group (IG; $n = 12$) or a Control Group (CG; $n = 16$). Over nine weeks, the IG completed two additional 50-minute sessions per week focused on progressive resistance training and functional aerobic exercises, while the CG followed the regular bi-weekly PE schedule. Pre- and post-intervention assessments included explosive strength, linear speed, agility, cardiorespiratory fitness, muscular endurance, and flexibility. Mixed-model analyses revealed significant Group $\times$ Time interactions favouring the IG for standing broad jump ($p<0.05$) and 40 m sprint performance ($p<0.05$), with a strong trend for agility ($p=0.05$). Between-group effect sizes were moderate to large (Cohen's $d=0.75$–0.93). No significant effects were found for flexibility, while cardiorespiratory fitness and muscular endurance showed positive but non-significant trends. These findings suggest that a third weekly neuromuscular training session is a feasible and effective strategy to enhance key performance-related fitness components in adolescents in school settings. However, results should be interpreted cautiously because of methodological limitations such as small sample size and lack of maturation control.

Keywords: Adolescents, Explosive strength, Neuromuscular training; Physical Education, Training frequency

Introduction

Physical activity during adolescence is fundamental for promoting motor development, musculoskeletal health, and the establishment of lifelong healthy habits (Bull et al., 2020). Despite broad consensus on its importance, a significant proportion of adolescents fail to meet the international recommendations for moderate-to-vigorous physical activity and, specifically, for muscle-strengthening activities (Guthold et al., 2020). In this context, the school environment emerges as a privileged and equitable setting for implementing interventions aimed at improving physical fitness, given its capacity to reach the entire youth population regardless of socioeconomic background (Pfledderer et al., 2021).

Strength and conditioning training for adolescents has gained substantial scientific support, being recognised as safe and effective for improving neuromuscular fitness when properly supervised and periodised (Lloyd et al., 2014; Stricker et al., 2020). Current evidence, derived from systematic reviews and meta-analyses, robustly demonstrates its benefits for increasing muscle strength and power (Behringer et al., 2011), sprint performance (Morin et al., 2019), and motor skill competency (Collins et al., 2019). However, a critical analysis of this body of literature reveals recurrent methodological limitations that compromise the internal validity of many studies and hinder the formulation of precise and generalisable practical guidelines.

A primary source of heterogeneity stems from the wide variation in training protocols. Factors such as exercise selection, intensity, volume, and weekly frequency differ considerably between studies (Moran et al., 2017), making it difficult to isolate the optimal dose-response relationship for specific outcomes. This methodological inconsistency is particularly pronounced in studies conducted in real-world school settings, where logistical constraints and the pedagogical nature of the environment often limit experimental control (Faigenbaum et al., 2013).

Furthermore, issues related to self-selection bias and varying levels of adherence are frequently underreported but significantly impact the interpretation of results and the assessment of intervention feasibility (Love et al., 2019). Many school-based studies lack a true inactive control group or fail to adequately control and describe the 'dose' of physical activity received by the control group, which typically continues with standard PE classes. This limitation obscures the specific effect of the additional training stimulus, highlighting the need for detailed reporting of intervention protocols and controlled training doses (Granacher et al., 2016). Consequently, there is a clear gap in the evidence regarding the efficacy of well-controlled, school-based interventions that precisely prescribe an additional neuromuscular training dose on top of the standard curriculum.

One specific and under-researched aspect within this gap is the definition of a minimum effective weekly frequency for inducing meaningful neuromuscular adaptations in adolescents. International public health guidelines recommend muscle-strengthening activities on at least three days per week (Bull et al., 2020), but the empirical basis for this specific frequency within school-based, time-constrained interventions remains less consolidated. While some reviews suggest that two weekly sessions may be sufficient for strength development (Faigenbaum et al., 2009), position statements specifically focused on youth resistance training indicate that a frequency of up to three non-consecutive sessions per week may be optimal for maximising muscular strength and, by extension, power-related adaptations (Lloyd et al., 2014). This uncertainty underscores the need for studies that directly test the additive effect of a third weekly training session against a control group maintaining only the standard biweekly PE routine. Clarifying this point has direct implications for curriculum planning and the efficient use of limited school resources.

It is also crucial to establish clear primary and secondary expectations based on the principle of training specificity. A program primarily focused on high-intensity neuromuscular exercises, with an emphasis on resistance training and power development, is theoretically designed to produce the most significant adaptations in strength, power, and speed-related tasks (Suchomel et al., 2016). While integrative neuromuscular training models, which incorporate a variety of conditioning activities to enhance fundamental movements and reduce injury risk, suggest potential concurrent improvements in other fitness domains (Myer, Faigenbaum, Ford, et al., 2011), adaptations in cardiorespiratory fitness or localised muscular endurance would be considered secondary outcomes. These secondary adaptations may require a different stimulus or longer intervention periods to manifest statistically significant changes.

Therefore, this study aims to address these identified gaps by implementing a controlled, school-based intervention. The primary objective was to evaluate the effect of adding a third weekly, structured neuromuscular training session on indicators of explosive strength, speed, and agility in adolescents, compared to a control group participating exclusively in standard PE classes. Secondary objectives included assessing the intervention's impact on cardiorespiratory fitness, muscular endurance, and flexibility. By employing a quasi-experimental design with a non-randomised control group, closely monitoring adherence, and applying a standardised training protocol, this study seeks to contribute more robust evidence on the efficacy and feasibility of supplementing the school physical activity curriculum with a defined additional training dose.

Methods

Study design

This study adopted a quasi-experimental, longitudinal design with a non-randomised control group, structured into four distinct phases: (i) design of the intervention programme; (ii) baseline assessment (pre-test) of the intervention and control groups; (iii) implementation of the physical exercise programme in the intervention group; and (iv) post-intervention assessment (post-test) of both groups.

Participants were allocated to groups on a voluntary basis, and no randomisation procedures were applied. Given the absence of random allocation and the constraints inherent to the school-based context, the study is appropriately classified as quasi-experimental.

Sample

The sample consisted of 28 students from the São Pedro Secondary School in Vila Real, 10 males and 18 females, with an average age of 17 years (±0.21). The participants were divided into two groups: the Intervention Group (IG) and the Control Group (CG). Inclusion criteria were: (i) enrolment in secondary education; (ii) regular attendance of PE classes; and (iii) provision of parental informed consent and participant assent. Exclusion criteria included: (i) presence of musculoskeletal injuries or medical conditions contraindicating physical exercise; (ii) absence from pre - or post-intervention assessments; and (iii) attendance of fewer than 50% of the intervention sessions in the IG. This attendance criterion was established as a pragmatic threshold to ensure a minimum exposure to the intervention while accounting for typical school absences.

Fifteen students voluntarily expressed interest in participating in the exercise programme and were initially allocated to the IG. However, only 12 participants met the minimum attendance requirement (≥50% of sessions) and completed all assessments and were therefore included in the final analysis. The remaining 16 students constituted the CG. The CG maintained their regular school routine, including standard PE classes, and did not participate in any additional structured physical activity intervention during the study period.

Intervention Programme

The intervention programme was designed by the researchers in accordance with international guidelines for physical exercise prescription in adolescents (Faigenbaum et al., 2009; Lander et al., 2017; Michaleff & Kamper, 2011). Sessions lasted approximately 50 minutes and were conducted twice per week (Tuesdays and Thursdays) over a 9-week period (18 sessions), within the school facilities.

The programme focused on general physical fitness, with particular emphasis on muscular strength and functional capacity. Training sessions included resistance exercises with systematic load progression (3-4 sets, 8-12 repetitions, 65-85% of one-repetition maximum), as well as aerobic and functional fitness challenges involving high-repetition, multi-joint movements. Training progression was implemented gradually throughout the programme, following the principles of progressive overload and individualisation.

All sessions were supervised by professionals holding a degree in Sport Sciences, ensuring technical accuracy, participant safety, and appropriate load prescription. Sessions were conducted in small groups (3-4 participants), allowing for close supervision and individualised feedback.

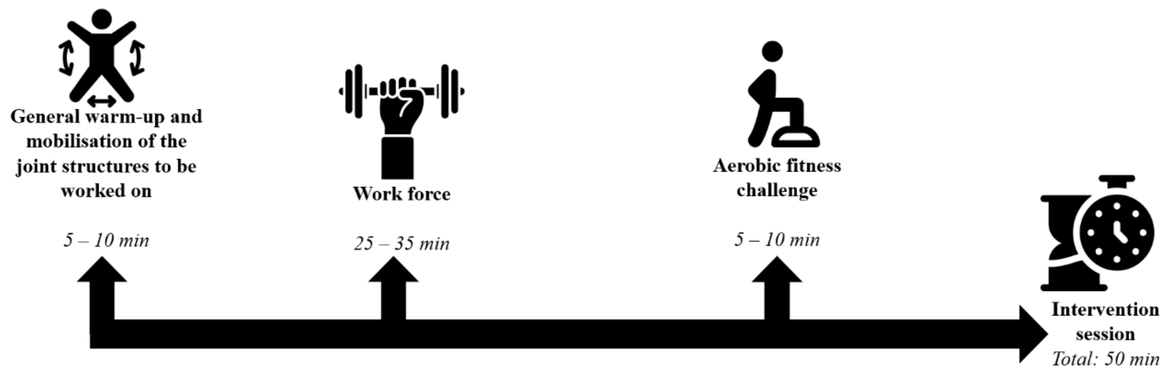

Figure 1. Example of a programme session. Strength training: two movements to choose from, of the 3 presented (squat, bench press, deadlift) for 3 to 4 sets, 8 to 12 repetitions, between 65 - 85% of RM; Aerobic fitness challenge: sets of varied movements and high repetition numbers (jumping rope, running, climbing the box, push-ups, etc.)

Ethical Considerations

All the procedures adopted in this study were conducted in accordance with the ethical principles established in the Declaration of Helsinki. The students' participation was voluntary, with the informed consent of their parents and the assent of the participants themselves. The study was previously authorised by the school management and approved by an institutional research ethics committee, in accordance with current regulations.

Statistical analysis

Statistical analyses were performed using SPSS software (version 27.0). Descriptive statistics included means and standard deviations. Data distribution was examined using skewness and kurtosis coefficients, and normality was assessed using the Kolmogorov-Smirnov test with Lilliefors correction. The assumption of homogeneity of variances was tested using Levene's test. Whenever the assumption of equal variances was violated, the Welch's t-test was applied. In addition to between-group comparisons at pre - and post-intervention time points, pre - post changes (Δ values) were calculated for all dependent variables and compared between groups, providing a more appropriate analysis for the longitudinal nature of the study design. Effect sizes (Cohen's d) were calculated for all outcome variables, allowing for the interpretation of the magnitude and practical relevance of the observed effects, independently of statistical significance. Effect sizes were interpreted according to conventional thresholds (small ≥0.2; moderate ≥0.5; large ≥0.8). Statistical significance was set at $p \leq 0.05$.

Results

Baseline comparisons (pre-test)

At baseline, no statistically significant differences were observed between groups for most variables ($p > 0.05$), indicating an overall comparable initial status. Mean values for body mass index, cardiorespiratory fitness (20 m Shuttle Run), lower-limb explosive strength (standing broad jump and vertical jump), muscular strength/endurance (press-ups and sit-ups), linear speed (40 m sprint), and flexibility (sit-and-reach) were similar between groups, with small to moderate effect sizes ($|d| \leq 0.70$).

The only exception was the 4 × 10 m Shuttle Run, in which the IG demonstrated superior performance compared to the CG ($p < 0.05$), accompanied by a large effect size ($d = -1.20$). This baseline difference indicates an initial advantage in agility that should be considered when interpreting post-test outcomes.

Table 1. Mean, standard deviation, absolute and relative differences, *t*-values, *p*-values, and effect sizes within groups at baseline (pre-test).

	Intervention (n=12)	**Control (n=16)**				
Tests	**x̄ (±sd)**	**x̄ (±sd)**	**Δ (%)**	***t***	***p***	***d***
Body Mass Index (kg/m²)	21,59 (2,94)	22,16 (3,48)	0,57 (2,56)	-0,45	0,65	-0,17
20 m Shuttle Run (number of shuttles)	61,00 (23,58)	48,31 (24,07)	12,69 (26,26)	1,39	0,09	0,53
Standing Broad Jump (cm)	195,25 (34,449	189,75 (34,67)	5,50 (2,90)	0,42	0,68	0,16
Vertical Jump (cm)	42,92 (9,82)	38,25 (9,77)	4,67 (12,20)	1,25	0,11	0,48
Press-Ups (number of repetitions)	21,58 (11,37)	22,06 (10,48)	0,48 (2,17)	-0,12	0,45	-0,04
Sit-Ups (number of repetitions)	67,50 (17,87)	70,69 (14,02)	3,19 (4,51)	-0,53	0,30	-0,20
Agility Shuttle Run 4 × 10 m (s)	11,09 (1,11)	12,53 (1,27)	1,44 (11,50)	-3,13	***0,00****	-1,20
40 m Sprint Test (s)	6,29 (0,63)	6,70 (0,68)	0,41 (6,13)	-1,64	0,11	-0,63
Sit-and-Reach | left (cm)	33,75 (9,29)	28,38 (8,75)	5,38 (18,94)	1,57	0,13	0,60
Sit-and-Reach | right (cm)	35,29 (8,97)	29,25 (8,35)	6,04 (20,66)	1,84	0,08	0,70

x̄ = mean, ±sd = standard deviation, Δ = between-group comparison of changes, % = percentage gains, *t* = independent samples t-test, *p* = significance level, kg = kilogram, m = meter, cm = centimeter, s = seconds, * = significant (p < 0,05), d = effect size (Cohen´s d).

Post-test comparisons

At post-test, the IG showed superior performance compared to the CG in several physical fitness outcomes, with statistically significant differences and effect sizes of moderate to large magnitude.

A significant between-group difference was observed for the standing broad jump ($p < 0.05$), with a large effect size ($d = 0.82$), indicating a substantial improvement in lower-limb explosive strength in the IG. Similarly, performance in the 4 × 10 m Shuttle Run remained significantly better in the IG ($p = 0.05$), with a moderate-to-large effect size ($d = -0.75$), suggesting a meaningful effect of the intervention on agility.

For the 40 m sprint, the IG achieved significantly faster times than the CG ($p < 0.05$), accompanied by a large effect size ($d = -0.93$), reflecting a pronounced improvement in linear speed.

Although no statistically significant between-group differences were found for cardiorespiratory fitness, vertical jump, press-ups, or sit-ups ($p > 0.05$), effect sizes ranged from moderate to moderately large ($0.39 \leq d \leq 0.57$), indicating favourable trends for the IG that may be practically relevant despite the absence of statistical significance.

In contrast, flexibility outcomes (sit-and-reach, left and right) showed neither statistically significant differences nor meaningful effect sizes ($d \leq 0.18$), suggesting minimal impact of the intervention on this capacity.

Table 2. Mean, standard deviation, absolute and relative differences, *t*-values, *p*-values, and effect sizes within groups at post-test.

	Intervention (n=12)	Control (n=16)				
Tests	**x̄ (±sd)**	**x̄ (±sd)**	**Δ (%)**	***t***	***p***	***d***
Body Mass Index (kg/m²)	22,15 (2,78)	22,16 (3,53)	0,01 (0,03)	-0,01	1,00	0,00
20 m Shuttle Run (number of shuttles)	67,83 (23,71)	56,94 (30,33)	10,90 (19,14)	1,03	0,16	0,39
Standing Broad Jump (cm)	217,17 (36,30)	190,06 (30,27)	27,10 (14,26)	2,15	***0,04****	0,82
Vertical Jump (cm)	47,00 (11,40)	42,19 (9,68)	4,81 (11,41)	1,21	0,12	0,46
Press-Ups (number of repetitions)	31,42 (14,36)	26,25 (9,94)	5,17 (19,68)	1,13	0,27	0,43
Sit-Ups (number of repetitions)	80,00 (0,00)	76,88 (7,18)	3,13 (4,07)	1,50	0,15	0,57
Agility Shuttle Run 4 × 10 m (s)	10,71 (0,79)	11,42v (1,04)	0,71 (6,21)	-2,05	**0,05***	-0,75
40 m Sprint Test (s)	6,05 (0,57)	6,73 (0,82)	0,68 (10,04)	-2,57	***0,02****	-0,93
Sit-and-Reach | left (cm)	30,67 (9,88)	29,56 (7,84)	1,10 (3,74)	0,33	0,74	0,13
Sit-and-Reach | right (cm)	32,00 (9,85)	30,44 (7,48)	1,56 (5,13)	0,48	0,64	0,18

x̄ = mean, ±sd = standard deviation, Δ = between-group comparison of changes, % = percentage gains, *t* = independent samples t-test, *p* = significance level, kg = kilogram, m = meter, cm = centimeter, s = seconds, * = significant (p < 0,05), d = effect size (Cohen´s d).

Summary of findings

Overall, the results indicate that the inclusion of a third weekly strength training stimulus was particularly effective in enhancing explosive strength, agility, and linear speed, as evidenced by the combination of statistically significant p-values and moderate-to-large effect sizes at post-test. For other fitness components, observed effect sizes suggest positive trends that warrant consideration in the Discussion, especially in light of the intervention duration and sample size.

Discussion

The results of the present study corroborate the central hypothesis that the inclusion of an additional neuromuscular stimulus in the school routine of adolescents promotes superior gains in critical physical capacities, such as explosive strength and speed, when compared to participation exclusively in conventional PE classes. It was observed that the IG showed significant improvement in the long jump (*p* < 0.05) and the 40-meter sprint (*p* < 0.02), demonstrating that a structured nine-week program is effective in inducing positive neuromuscular adaptations in youth. On the other hand, the CG, which maintained only regular PE classes, did not show significant improvements in these parameters, reinforcing the idea that the volume and intensity of curricular classes may be insufficient to optimise the development of these capacities in adolescents.

The magnitude of the improvement in the long jump and sprint speed observed in the IG has important practical implications, not only for sports performance but also for musculoskeletal health and injury prevention in this population, a benefit widely recognised in the scientific literature (Lloyd et al., 2014).

This evolution in lower limb strength and power is consistent with the scientific literature that highlights the plasticity of the neuromuscular system during adolescence. According to Behringer et al. (2011), resistance training in this age group is one of the most effective methods for motor development, as long as load progression is respected. In the applied program, the use of complex multi-joint exercises, such as squats and deadlifts, served as the foundation for improving motor unit recruitment and intramuscular coordination, directly reflecting improvements in field test performance. It is important to emphasise that the absence of adverse events during the intervention supports recent findings and the longstanding consensus that supervised and periodised strength training is safe and highly beneficial for adolescents (Lloyd et al., 2014; Stricker et al., 2020).

The connection between the increase in strength and the improvement in linear speed observed in the IG also finds theoretical support. The increased capacity to produce force against the ground is a fundamental determinant for acceleration and maximum speed in young athletes and students (Granacher et al., 2016). While the CG maintained stable results, the IG managed to significantly reduce its sprint times, suggesting that the third weekly 'dose' of exercise was the differential needed to overcome the plateau in physical development imposed by the traditional school curriculum. This finding aligns with the concept of training 'transfer,' where gains in maximum and explosive strength are reflected in specific tasks requiring high power, such as short-distance sprints (Morin et al., 2019). The effectiveness of a frequency of 2-3 sessions per week, as implemented in this study, is a cornerstone of established youth resistance training guidelines (Lloyd et al., 2014).

Moreover, recent reviews corroborate the importance of adequate weekly frequency for optimising neuromuscular adaptations in adolescents. Faigenbaum et al. (2015) emphasise that a frequency of three weekly sessions is a key component for maximising strength, power, and speed gains in youth, provided it is accompanied by appropriate supervision and load progression. This theoretical support reinforces that the third weekly stimulus implemented in the present study was likely the differential factor in overcoming the developmental plateau imposed by the traditional school curriculum and producing significant improvements in critical physical capacities.

However, it is important to note that capabilities such as muscular endurance (sit-ups and push-ups) and cardiorespiratory fitness showed positive trends and moderate effect sizes, but the Group × Time interaction was not statistically significant (*p* > 0.05). This phenomenon may be attributed to the duration of the intervention or the small sample size, which limits the statistical power to detect smaller changes in these specific variables. Additionally, the nature of the program - with a predominant focus on high-intensity, low-volume neuromuscular exercises - may not have provided an optimal stimulus for central (cardiovascular) and localised muscular endurance adaptations over the long term. Still, the effect sizes (Cohen's *d*) between 0.39 and 0.57 suggest that neuromuscular training exerts a beneficial influence on general endurance, consistent with the notion that integrative training programs can promote simultaneous improvements in health - and performance-related fitness components, even when neuromuscular gains are the primary focus, as discussed by Myer et al. (2011) in their integrative training model for youth.

On the other hand, the absence of improvements in flexibility levels highlights the specificity of the training applied. The program's focus on strength exercises and high-repetition aerobic challenges did not include systematic long-duration stretching or mobility protocols, resulting in negligible effect sizes in this variable. This finding reinforces the need for more holistic interventions in the school context, which balance strength development with the maintenance of joint range of motion, especially during a phase of accelerated growth where muscle shortening is common (Faigenbaum et al., 2009). It is suggested that future school programs integrate brief dynamic stretching sessions during warm-ups and static stretching at the end of each session, or incorporate strength training through full ranges of motion, as a strategy to mitigate this deficit (Afonso et al., 2021).

Despite the positive results observed, an important limitation of this study was the lack of control of biological maturation. In adolescents with an average age of 17 years, variability in maturational status may influence the magnitude of neuromuscular adaptations, since young people at different stages respond differently to the same training stimulus due to hormonal and structural variations (Lloyd et al., 2014). This influence is critical, as performance in explosive strength and speed tests is strongly conditioned by maturational status and may act as a confounding variable in the interpretation of gains attributed exclusively to the intervention (Radnor et al., 2017). In addition, the literature indicates that the timing of maturation interacts directly with adaptations to strength training and subsequent detraining (Meylan et al., 2014), suggesting that future studies should include methods of assessing maturation to isolate the effect of the program from the natural biological changes inherent to this age group.

In short, implementing a third weekly 50-minute stimulus addresses an important gap in physical activity guidelines for adolescents. As recommended by Bull et al. (2020), young people should engage in muscle-strengthening activities at least three times a week. The data presented here demonstrate that the school environment, through supervised, small-group sessions, is a privileged setting for combating physical inactivity and promoting motor literacy, ensuring that students achieve levels of physical fitness consistent with long-term health and well-being. Therefore, integrating structured neuromuscular training programs into the school curriculum emerges not as an extra, but as an essential component of a contemporary and truly health-promoting PE.

This study has other limitations that should be considered, such as the absence of randomisation in group formation, the aforementioned lack of control for participants' biological maturation, the permissive adherence criterion, and the failure to assess parameters such as body composition or adherence to physical activity outside of school. Future research with larger samples, randomised designs, longer intervention periods, and follow-up is needed to investigate the sustainability of gains and the impact on other health markers.

Conclusion

The results of this study suggest that implementing a structured neuromuscular training program as a third weekly stimulus in the school setting may promote significant improvements in explosive strength, agility, and linear speed among adolescents, compared to participation in regular PE classes alone. These findings reinforce the potential of using the school context to complement physical activity recommendations for this population, with possible benefits for motor development and musculoskeletal health. However, due to methodological limitations - such as the absence of randomisation, the small sample size, and the lack of control for biological maturation - the conclusions should be considered preliminary and not generalisable. Thus, although promising, the results highlight the need for future studies with greater methodological rigour, larger samples, and longer intervention periods to confirm the effectiveness and sustainability of this approach within the school environment.

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