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Effects of Different Periodization Models in Strength Training on Physical and Motor Skills during 24 Weeks of Training

Efeitos de diferentes modelos de periodização em treinamento de força sobre capacidades físicas e motoras durante 24 semanas de treinamento

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Abstract

Introduction: Periodization is the accurate manipulation of methodological variables of strength training (ST) to provide a progressive increase in the different manifestations of muscle strength. The most used models in ST are linear and undulatory periodization.

Objective: Evaluate the effects of 24 weeks of training by applying three different models of ST periodization: Linear Periodization (LP), Weekly Undulating Periodization (WUP) and Daily Undulating Periodization (DUP) on: upper limb (UL) strength (submaximal and endurance), submaximal strength and power of the lower limbs (LL) and on other components of physical fitness (flexibility, agility and abdominal endurance strength).

Methods: Experimental, longitudinal study, with a convenience sample, in which 29 people of both sexes participated, randomly allocated to the groups. Tests were performed pre- and post-intervention. ANOVA (two-way) of repeated measures was performed.

Results: There was a significant increase in submaximal strength of the UL in the three periodization models: LP ($p < 0.001$), the WUP ($p = 0.002$) and DUP ($p = 0.001$). There was also a significant increase in submaximal strength of the LL with LP ($p = 0.002$), WUP ($p < 0.001$) and with DUP ($p = 0.001$). No significant intergroup differences were found in any test and time.

Conclusion: In individuals without training experience, 24 weeks of TF provided gains in different manifestations of strength, regardless of the periodization model (LP, WUP or DUP). LP and WUP seem to be better at providing LL power gains in the horizontal jump.

Key Points

- Longitudinal experimental study lasting 24 weeks.
- There was a significant increase in upper limb submaximal force in the three periodization models.
- There was a significant increase in submaximal strength of the lower limbs in the three periodization models.

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Keywords: physical training; physical exercise; training activities; physical training planning.

Resumo

Introdução: Periodização é a manipulação adequada das variáveis metodológicas do treinamento de força (TF), para proporcionar o aumento progressivo das diferentes manifestações de força muscular. Os modelos mais utilizados no TF são a periodização linear e a ondulatória.

Objetivo: Avaliar os efeitos de 24 semanas de treinamento aplicando três modelos distintos de Periodização em TF: Linear (PL), Ondulatória Semanal (POS) e Ondulatória Diária (POD) sobre: força (submáxima e de resistência) de membros superiores (MMSS), força submáxima e potência de membros inferiores (MMII) e sobre outros componentes da aptidão física (flexibilidade, agilidade e força de resistência abdominal).

Métodos: Estudo experimental, longitudinal, com amostra por conveniência, do qual participaram 29 pessoas de ambos os sexos, alocados aleatoriamente nos grupos. Os testes foram realizados pré e pós-intervenção. Realizou-se ANOVA (*two-way*) de medidas repetidas.

Resultados: Houve aumento significativo em força submáxima de MMSS nos três modelos de periodização: PL ($p<0,001$), a POS ($p=0,002$) e POD ($p=0,001$). Houve, também, aumento significativo em força submáxima de MMII com PL ($p=0,002$), POS ($p<0,001$) e com POD ($p=0,001$). Não foram encontradas diferenças significativas intergrupos em nenhum teste e momento.

Conclusão: Em indivíduos sem experiência em treinamento, 24 semanas de TF proporcionaram ganhos em diferentes manifestações de força, independente do modelo de periodização (PL, POS ou POD). A PL e a POS parecem ser melhores para proporcionar ganhos em potência de MMII no salto horizontal.

Palavras-chave: treinamento físico; exercício físico; atividades de treinamento; planejamento de treinamento físico.

Pontos Chave

- Estudo experimental longitudinal com 24 semanas de duração.
- Houve aumento significativo em força submáxima de MMSS nos três modelos de periodização.
- Houve aumento significativo em força submáxima de MMII nos três modelos de periodização.

Effects of Different Periodization Models in Strength Training on Physical and Motor Skills during 24 Weeks of Training

Introduction

Appropriate manipulation of the methodological variables considered in the planning of strength training (ST) provides progressive increase in the different manifestations of muscle strength (maximal strength, power, hypertrophy and endurance)(1). Training periodization, an integral part of planning, aims to design actions and carry out specific adjustments with a view to optimizing physical performance and preventing overtraining(2). In previous studies addressing periodization, it is observed that the most commonly investigated models relate to linear (or traditional) and nonlinear (or undulating) periodization(3). The former is characterized by constant increases in the training load with a simultaneous reduction in volume, spread out over the training cycles(4). The undulating model is characterized by

frequent changes in training volume and intensity, whether weekly, by cycles or even daily(4). There is a wide range of studies addressing the subject of periodization and comparison between its different models(5–8), with intervention being most frequently applied in up to 16 weeks of training. Another factor observed in studies on periodization is that the most commonly analyzed variables are maximal and submaximal strength(6–8), noting that, in practice, both in physical training and in sports performance, muscle actions that require the use of maximal strength are not very common. This observation indicates that muscle functionality is more closely related to submaximal strength (9), which emphasizes the relevance of studying the application of different training methods in the development of strength. Additionally, ST can contribute to improve other physical fitness components such as: speed, agility,

balance, coordination, power and flexibility, besides improving motor performance(10). A gap is observed in the literature regarding the use of different periodization models with different physical abilities in periods longer than three months, which justifies the relevance of studying the subject. An experimental study using a 24-week intervention period showed that a daily undulating periodization protocol provides greater gain in lower limb strength, while weekly undulating periodization proved to be more efficient in increasing lower limb power(11).

This study examined the effects of three periodization models for ST: linear periodization, weekly undulating periodization and daily undulating periodization on upper limb (UL) submaximal strength and endurance and lower limb (LL) submaximal strength and power, and explored the effects on other physical fitness components (flexibility, agility and abdominal endurance).

Methods

Study design and sample

This was a longitudinal-experimental study with a 24-week intervention period. Convenience sampling was used with physical education undergraduate students of the Federal University of Pará (UFPA). The participants were randomly assigned to the three intervention groups: a) Linear Periodization (LP); Weekly Undulating Periodization (WUP); and c) Daily Undulating Periodization (DUP).

The inclusion criteria were: no experience with ST and no history of osteomioarticular lesions. The exclusion criteria were: having a functional limitation to performing the proposed exercises; having any medical condition that might prevent the performance of the experimental conditions. In addition, individuals with an absence rate during training above 25% and who missed three consecutive training sessions during the 24 weeks were considered sample loss. Missed training sessions were replaced on Wednesdays or Saturdays.

Ethical aspects

The project was submitted to the Research Ethics Committee under CAAE number 70890717.3.0000.0018, in accordance with resolution 466/2012 of the Brazilian National Health Council for research with human beings.

Study variables

The main dependent variables were: upper limb (UL) and lower limb (LL) submaximal strength, UL endurance and LL power. The secondary dependent variables were: abdominal endurance, flexibility and agility.

The independent variable was the experimental intervention, consisting of three periodization models of strength training: LP, WUP and DUP. Age, body mass and height were the covariates used to characterize the sample.

Upper limb (UL) and lower limb (LL) submaximal strength

The 10 Repetition Maximum Test (10-RM) was used to assess submaximal strength, using bench press (S10RM) for UL and 45° leg press (L10RM) for LL, described in detail in an experimental procedure(12).

Upper limb (UL) endurance

The push-up test (FBR) was used to assess upper limb endurance(15,16). Participants lay face down with their hands on the floor, at a distance of 10 to 20 cm from the line of the shoulders, fingers facing forward. The position of the hands on the floor must not be above the line of the shoulders and, in the initial movement position, the face must allow adequate alignment between the trunk and legs(13). For women, the only change is the contact of knees on the floor. The other procedures are performed for both genders. The maximum number of correct repetitions in one minute is recorded(14).

Lower limb (LL) power

Two tests were used to assess lower limb power: vertical jump and horizontal jump. The Sargent Jump Test (SJT) was used to assess lower limb power in the vertical jump(15). The fingers of the participant's right hand are chalked for the initial marking of the test. The participant stands laterally to the wall, keeping the feet completely on the ground, reaches the

right hand above the head as high as possible and marks that point on the wall. After the initial marking, the participant performs a vertical jump, during which he/she is allowed to freely flex the lower limbs and upper limbs, in order to jump as high as possible, marking the point reached with the chalked fingers. The measure of the participant's performance is given by the difference between the two points marked on the wall. The jump is repeated three times, with a resting interval of 45 seconds between jumps. According to the test methodology, the highest mark obtained in the three attempts is considered(15).

The horizontal jump test (SHO) was used to assess lower limb power in the horizontal jump (16). In the test, the participant stands behind a line with the feet parallel and slightly apart, approximately the width of the shoulders. At the command to "start," the participant performs the jump by bending the knees and swinging the arms in order to obtain the maximum forward drive. The distance was measured with a 25-m fiberglass tape measure from the starting line to the nearest heel point. According to the test methodology, three attempts are performed, and the longest distance obtained is considered(16).

Flexibility

The Sit and Reach test was used to assess flexibility, according to the Canadian Standardized Test of Fitness(17). The test is performed with a box measuring 30.5 cm x 30.5 cm x 30.5 cm with a 26-cm measuring rod on its extension. The zero point lies at the end closest to the participant and the twenty-sixth centimeter mark at the point where the feet are placed. The participants performed the tests barefoot, in a sitting position, with their feet placed flat against the box and their knees extended. With shoulders flexed, elbows extended and hands overlapped, they reach forward as far as possible and touch the measuring rod with their hands. Three attempts were made and only the best mark was considered.

Abdominal endurance

The Abdominal Test (Supra) in 1min (ABD) was used(18) to assess abdominal endurance. The participant lies on his/her back with the knees bent at 90 degrees and with the arms

crossed over the chest. The evaluator anchors the participant's feet to the ground. At the signal, the participant starts raising the trunk until he/she touches the elbows on the thighs, returning to the initial position (it is not necessary to touch the head on the mat each time). The evaluator counts out aloud. The participant must perform as many complete repetitions as possible in one minute. The result is expressed by the number of complete movements performed in one minute(18).

Agility

Two tests were used to assess the agility motor skill: the Shuttle Run Test (sudden change of direction in 180°) and the Illinois Agility Test (running with change of direction and position). The Shuttle Run Test (SHRN) involves performing a sudden change of direction in 180°. Two parallel lines are marked on the ground, 9.14 meters apart. Two cones are placed 10 centimeters from the outer line and spaced 30 centimeters apart. On the "go" signal the participant runs as fast as possible to the two cones placed at an equal distance from the outer line, picks up one of them and returns to the starting point, placing this cone behind the line. Then, without stopping, goes back to pick up the second cone, proceeding in the same way. The stopwatch is stopped after the participant places the second cone behind the start line. Three attempts are made with a one-minute interval between them, and the best performance time is considered (19).

The Illinois Agility Test (IL) involves running and changing position and direction. The test is set up with four cones that form the agility area, 10 meters long by 5 meters wide. Four cones are placed at each corner of the test area and four cones are placed in the center of the test area, 3.3 meters apart. The participant starts the test by lying face down by the starting cone, with hands at shoulder level and flexed elbows. At the whistle signal, the participant gets up and runs the course on the defined path in the shortest time possible. The test ends when the participant crosses the finish line without knocking down any cones(20).

Anthropometric measurements

Height and body mass measurements were taken to characterize the sample.

Intervention

The independent variable was intervention, which consisted of three distinct periodization models proposed for ST: LP, WUP and DUP.

Four weekly sessions were held, with training subdivided between a training protocol for UL and a training protocol for LL. The training sessions lasted an average of 45 minutes. The structure of the experimental intervention in ST according to the periodization models is presented in Chart 1.

Experimental procedure

The participants were randomly divided into three groups: LP (n=7), WUP (n=6) and DUP (n = 6). Six visits to the laboratory were made before the beginning of the 24-week training for familiarization with both the exercises and the 10 repetition maximum tests. Chart 2 presents the experimental protocol flow.

During the first visit to the laboratory, an explanation of the experimental procedure was given and the consent form was signed.

Forty-eight hours after the last familiarization session, the first visit of the test week was made for body mass (kg) and height (m) measurement. Body mass (kg) was measured on a Toledo 2096 PP digital scale (São Bernardo do Campo, SP, Brazil) while height (cm) was measured on a Wiso stadiometer (Florianópolis, SC, Brazil). These variables were measured only in the pre-experimental period to characterize the group. In addition, the following tests were performed: Sit and Reach (flexibility), Sargent Jump and horizontal jump (LL power), push-up (UL endurance), 1-min abdominal (abdominal endurance), Shuttle Run and Illinois Agility (agility).

On the second visit, the 10 repetition maximum (10RM) bench press and 45° leg press tests were performed. After the familiarization session with the proposed exercises (bench press and 45° leg press), all subjects performed a familiarization session with the 10RM test protocol with a 48-hour interval between sessions. The first 10RM test was performed on one day and after 48 hours a second 10RM test was performed to verify possible reproducibility between test-retest. The highest load achieved between the two days was considered the 10RM pre-training.

The subjects did not perform any exercise in the interval between the two test days. Five attempts at most of the 10RM test were performed with a five-minute interval between them and 10 minutes between exercises. If one of the exercises required a sixth attempt, it was done on another day after a 48-hour break(21).

On the third visit the 10RM retests were performed.

There was a 48-hour recovery interval between visits and also between the 10RM retest and the beginning of the training session. Every eight weeks these tests were redone to assess physical fitness and readjust the intensity of the participants' training. Thus, the assessments were performed before the beginning of the training sessions (pre), on week 8, on week 16, and at the end of the 24 weeks (post), totaling four assessments over the 24 weeks(11) (Chart 1).

Training Sessions

Following the interval of 48 to 72 hours of the 10RM retest, the training sessions were started. Each participant was randomly assigned to one of the experimental groups (LP, WUP and DUP) and performed a total of 96 sessions over the 24 weeks. The recovery intervals (RI) between sets and exercises followed the recommendations of the American College of Sports Medicine(22), namely: sixty seconds for Local Muscular Endurance (LME), 90 seconds for hypertrophy and three minutes for muscle strength. The upper limb exercises, used in subdivision A, were bench press with barbell, fly machine, triceps cable pressdowns, front pulldown, seated rows and barbell curl. The lower limb exercises used in subdivision B were leg curl machine, squat on the Smith Machine, 45° Leg Press, standing plantar flexion on the machine and sit-ups.

Statistical analysis

Values were expressed as mean and standard deviation. Data distribution normality was analyzed using the Shapiro-Wilk test. An ANOVA (one-way) was applied to analyze the significant difference between the groups in the Pre period and the ANOVA (two-way) of repeated measures with Bonferroni post hoc was applied to analyze the differences between the different test periods (Pre, week 8, week 16

LINEAR PERIODIZATION (LP)

WEEKS	Monday UL SUBDIVISION A	Tuesday LL SUBDIVISION B	Wednesday	Thursday UL SUBDIVISION A	Friday LL SUBDIVISION B
PRE			TESTS		
2 to 7	3 x 12–15RM		Rest		3 x 12–15RM
8			TESTS		
9 to 15	4 x 4–5RM		Rest		4 x 4–5RM
16			TESTS		
17 to 23	3 x 8–10RM		Rest		3 x 8–10RM
24			TESTS		

WEEKLY UNDULATING PERIODIZATION (WUP)

WEEKS	Monday UL SUBDIVISION A	Tuesday LL SUBDIVISION B	Wednesday	Thursday UL SUBDIVISION A	Friday LL SUBDIVISION B
1, 4, 7, 11, 14, 18, 21	3 x 12–15RM		Rest		3 x 12–15RM
2, 5, 9, 12, 15, 19, 22	4 x 4–5RM		Rest		4 x 4–5RM
3, 6, 10, 13, 17, 20, 23	3 x 8–10RM		Rest		3 x 8–10RM
PRE, 8, 16, 24			TESTS		

DAILY UNDULATING PERIODIZATION (DUP)

WEEKS	Monday UL SUBDIVISION A	Tuesday LL SUBDIVISION B	Wednesday	Thursday UL SUBDIVISION A	Friday LL SUBDIVISION B
1, 4, 7, 11, 14, 18, 21	3 x 12–15RM		Rest		3 x 8–15RM
2, 5, 9, 12, 15, 19, 22	4 x 4–5RM		Rest		3 x 12–5RM
3, 6, 10, 13, 17, 20, 23	3 x 8–10RM		Rest		4 x 4–10RM
PRE, 8, 16, 24			TESTS		

Chart 1 – Experimental intervention in strength training (ST) according to periodization models: linear periodization (LP), weekly undulating periodization (WUP) and daily undulating periodization (DUP).

UL: upper limbs; LL: lower limbs; RM: repetition maximum.

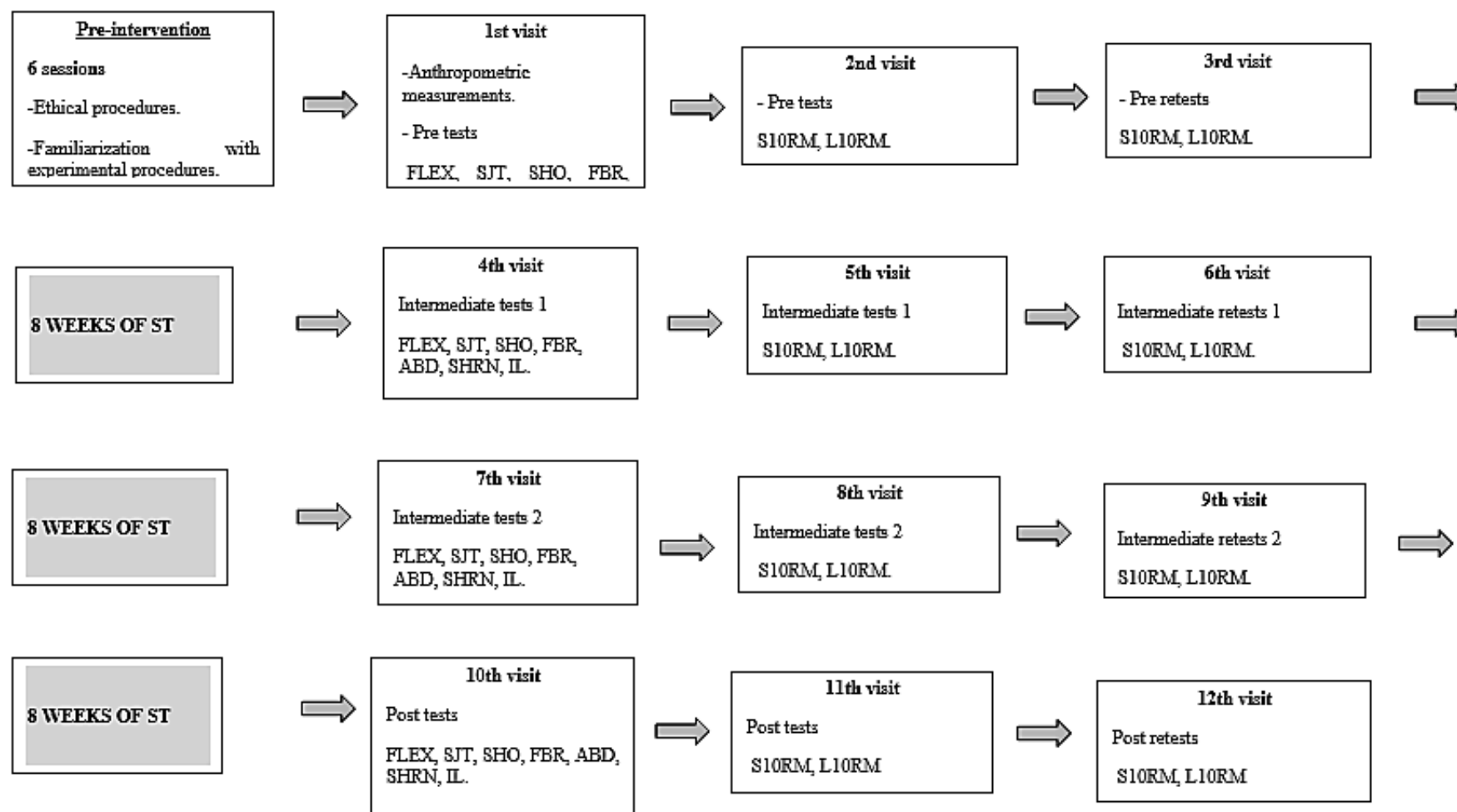


Chart 2 – Flowchart of the experimental protocol for comparing the effects of three different periodization methods in strength training (ST): Linear Periodization (LP); Weekly Undulating Periodization (WUP); and Daily Undulating Periodization (DUP)

FLEX: sit and reach test (flexibility); **SJT:** Sargent Jump Test (lower limb (LL) power in vertical jump); **SHO:** horizontal jump (LL power in horizontal jump); **FBR:** push-up test (upper limb (UL) endurance); **ABD:** 1-minute abdominal test (abdominal endurance); **SHRN:** Shuttle Run (agility: direction); **IL:** Illinois Agility Run (agility: direction in motion); **S10RM:** 10 repetitions at maximum load in bench press (UL submaximal force); **L10RM:** 10 maximum repetitions in 45° Leg press (lower limb (LL) submaximal strength).

and Post) in the different periodization models. The alpha value used for all steps of the experimental analysis was $p \leq 0.05$. SPSS software for Mac Version 22.0 (SPSS Inc., Chicago, IL, USA) was used in all statistical analyses.

Results

Of the 45 subjects invited to participate in the study there was a loss of 26 participants for missing more than 25% of the training sessions. Thus, the sample consisted of 19 participants (9 women and 10 men). The characteristics of the volunteers are shown in Table 1.

Table 1 – Characterization of the sample and breakdown of participants by intervention group: Linear Periodization (LP), Weekly Undulating Periodization (WUP) and Daily Undulating Periodization (DUP) (n=19)

Group	Age (years)	Body mass (kg)	Height (m)
LP	23 ± 3.20	59.70 ± 4.20	1.66 ± 0.05
WUP	24 ± 2.10	65.10 ± 8.70	1.69 ± 0.10
DUO	23 ± 1.70	65.80 ± 3.90	1.70 ± 0.10

LP: Linear Periodization; WUP: Weekly Undulating Periodization; DUP: Daily Undulating Periodization; kg: kilogram; m: meter.

The results of the assessments in the different test periods for the three groups are shown in Table 2. No differences were found between the groups in the pre-intervention period in UL ($p=0.256$) and LL submaximal strength ($p=0.887$), UL endurance ($p=0.426$) and LL power in vertical ($p=0.352$) and horizontal jump ($p=0.478$), neither in direction agility ($p=0.410$) and direction agility with movement ($p=0.285$), flexibility ($p=0.676$) and abdominal endurance ($p=0.560$). No significant intergroup differences (LP, WUP and DUP) were found in any stage (Pre, Week 8, Week 16 and Post), in any of the tests.

In abdominal endurance, in the LP group, significant differences were observed in the pre period compared to week 16 ($p=0.050$); pre compared to the post period ($p=0.009$); week 8 compared to the post period ($p=0.001$); and week 16 compared to the post period ($p=0.004$). In the WUP group, significant differences were observed in the pre period compared to week 16 ($p=0.011$); pre compared to the post period ($p=0.004$); and week 8 compared to the post period ($p=0.021$). In the DUP group, significant differences were observed in the pre period compared to the post period ($p=0.050$).

Regarding flexibility, there was a significant difference only for the WUP group between the pre and week 8 periods ($p=0.023$).

In agility, significant differences were observed in abrupt change of direction (Shuttle Run Test) in the LP group: between the pre and post periods ($p=0.003$) and between week 8 and the post period ($p=0.006$); in the WUP group: significant differences were observed in week 8 compared to the post period ($p=0.038$); and in the DUP group: significant differences were observed only between the pre and post periods ($p=0.020$).

In UL submaximal strength, the LP group showed significant differences between the pre period and week 8 ($p<0.001$); between the pre period and week 16 ($p=0.003$); between the pre and post periods ($p<0.001$); between week 8 and week 16 ($p=0.027$); and between week 8 and the post period ($p=0.003$). In the WUP group, significant differences were observed between the pre and week 8 periods ($p=0.003$); between the pre period and week 16 ($p=0.006$); between the pre and post periods ($p=0.002$); between week 8 and the post period ($p=0.007$); and between week 16 and the post period ($p=0.007$). For the DUP group, significant differences were observed between the pre and week 8 periods ($p=0.007$); between the pre

period and week 16 ($p=0.002$); between the pre and post periods ($p=0.001$); between weeks 8 and 16 ($p=0.009$); between week 8 and the post period ($p=0.002$); and between week 16 and the post period ($p=0.014$).

In LL submaximal strength, the LP group showed significant differences between the pre period and week 8 ($p=0.014$); between the pre period and week 16 ($p=0.006$); between the pre and post periods ($p=0.002$); between week 8 and the post period ($p=0.009$); and between week 16 and the post period ($p=0.015$). In the WUP group, significant differences were observed between the pre period and week 16 ($p=0.004$); between the pre and post periods ($p<0.001$); between weeks 8 and 16 ($p=0.012$); between week 8 and the post period ($p=0.001$); and between week 16 and the post period ($p=0.002$). In the DUP group, significant differences were observed between the pre period and week 8 ($p=0.003$); between the pre period and week 16 ($p=0.003$); between the pre and post periods ($p=0.001$); between weeks 8 and 16 ($p=0.010$); between week 8 and the post period ($p=0.001$); and between week 16 and the post period ($p=0.001$).

Regarding LL power in horizontal jump, significant differences were observed in the LP group and in the WUP group between the pre period and week 8 ($p=0.031$ and $p=0.001$, respectively); between the pre period and week 16 ($p=0.024$ and $p=0.023$); and between the pre and post periods ($p=0.046$; and $p=0.015$).

In the DUP group, in turn, no significant intragroup differences were observed, i.e., in the results between periods. Regarding LL power in vertical jump, there were no significant intragroup differences for any of the periodization models.

In UL endurance, the LP group showed significant differences between the pre and post periods ($p=0.004$) and between week 8 and the post period ($p=0.002$). In the WUP group, significant differences were observed between the pre and post periods ($p=0.039$); between weeks 8 and 16 ($p=0.025$); between week 8 and the post period ($p=0.007$); and between week 16 and the post period ($p=0.004$). In the DUP group, significant differences were observed between the pre period and week 16 ($p=0.005$); between the pre

and post periods ($p=0.008$); and between week 8 and the post period ($p=0.046$) (Table 3).

Discussion

The main finding of this study was that for inexperienced subjects, after 24 weeks of ST there was a significant increase in UL and LL submaximal strength for the three periodization models of the experiment (LP, WUP and DUP) (Table 2). These findings corroborate previous studies that showed that for untrained or recreationally trained subjects(23) there was no difference in maximal strength gain when comparing the use of different periodization models (6,24). Other authors found similar results even in subjects with different characteristics, such as athletes(25–27), individuals with experience in ST(28,29) and sedentary individuals(30).

In this study, the results in submaximal strength gain observed in all periodization models are in accordance with studies on maximal strength, as there is a strong correlation between maximal and submaximal strength(31). In addition, in untrained subjects, this relationship seems to be even stronger and to increase after a period of ST(32), and, in functional terms, it is more important to improve the ability to exert force against light loads, that is, to increase submaximal strength(9).

It is noteworthy that for subjects with experience in ST, studies suggest that undulating periodization has an advantage over the linear model in maximal strength gain(7,8). However, for individuals without experience in ST, as is the case in this study, systematic reviews do not show significant differences between the linear and undulating periodization models, corroborating our results(4,33).

Regarding LL power gain, distinct results were observed in horizontal and vertical jump: no significant gain was found in vertical jump and there was a significant increase in LL power in horizontal jump when comparing performance in the pre-test period to weeks 8 and 16 and the post-test period, in both LP and WUP, which was not observed in DUP (Table 2). These findings can be explained by the different muscle activation patterns involved

Table 2 – Upper limb (UL) and lower limb (L) submaximal strength and LL power in vertical and horizontal jump according to the strength training (ST) periodization model (n=19)

Assessment	Stage	Linear Periodization (LP) (n = 7)	Weekly Undulating Periodization (WUP) (n = 6)	Daily Undulating Periodization (DUP) (n = 6)
UL submaximal strength ^a	Pre	23.14 ± 9.73	29.16 ± 14.86	35.16 ± 13.02
	Week 8	25.71 ± 9.70*	36.50 ± 17.08*	39.16 ± 13.02*
	Week 16	31.00 ± 13.16*&	40.16 ± 17.90*	46.50 ± 15.12*&
	Post	33.00 ± 12.75*&	43.16 ± 18.96*&£	49.50 ± 13.64*&£
LL submaximal strength ^b	Pre	114.57 ± 59.11	126.66 ± 55.73	127.00 ± 38.75
	Week 8	138.85 ± 74.35*	144.66 ± 57.22	164.33 ± 43.73*
	Week 16	162.28 ± 81.50*	169.33 ± 66.71*&	200.00 ± 50.99*&
	Post	192.00 ± 85.60*&£	208.33 ± 61.12*&£	233.00 ± 57.15*&£
LL vertical jump power ^c	Pre	0.34 ± 0.07	0.39 ± 0.13	0.43 ± 0.09
	Week 8	0.41 ± 0.09	0.44 ± 0.15	0.44 ± 0.13
	Week 16	0.39 ± 0.05	0.48 ± 0.14	0.44 ± 0.08
	Post	0.38 ± 0.06	0.51 ± 0.15	0.44 ± 0.10
LL horizontal jump power ^d	Pre	1.45 ± 0.39	1.69 ± 0.41	1.66 ± 0.34
	Week 8	1.54 ± 0.35*	1.85 ± 0.45*	1.87 ± 0.44
	Week 16	1.61 ± 0.31*	1.88 ± 0.48*	2.01 ± 0.52
	Post	1.58 ± 0.32*	1.88 ± 0.45*	1.82 ± 0.26

^a**S10RM Test**: 10 repetition maximum in bench press; ^b**L10RM test**: 10 repetition maximum in 45° Leg Press; ^c**SJT**: Sargent Jump test; ^d**SHO**: horizontal jump test. *Significant difference from the pre period; & Significant difference from week 8; £ Significant difference from week 16.

Table 3 – Mean and standard deviation of intragroup stages in the Endurance, Flexibility and Agility tests

Assessment	Stage	Linear Periodization (n = 7)	Weekly Undulating Periodization (n = 6)	Daily Undulating Periodization (n = 6)
UL endurance ^a	Pre	19.42 ± 10.69	25.00 ± 8.22	19.00 ± 6.22
	Week 8	22.00 ± 5.62	26.00 ± 5.72	26.33 ± 8.16
	Week 16	23.57 ± 4.82	31.66 ± 7.60*&	31 ± 6.92*
	Post	27.42 ± 6.57*&	34.16 ± 7.62*&£	33.33 ± 7.44*&
Abdominal endurance ^b	Pre	24.57 ± 12.50	30.16 ± 7.35	29.33 ± 8.91
	Week 8	29.85 ± 6.93	30.50 ± 7.68	34.83 ± 11.85
	Week 16	31.71 ± 12.85*	34.83 ± 7.16*	34.66 ± 6.25*
	Post	37.14 ± 10.10*&£	37.16 ± 9.10*&	36.83 ± 9.47*
Flexibility ^c	Pre	31.28 ± 6.73	28.5 ± 4.49	28.16 ± 8.95
	Week 8	30.64 ± 5.22	33.08 ± 3.90*	30.58 ± 9.59
	Week 16	31.35 ± 6.70	35.00 ± 7.70	31.75 ± 11.27
	Post	29.32 ± 6.92	36.00 ± 7.56	32.00 ± 10.2
Agility (change in direction and position) ^d	Pre	19.01 ± 2.32	17.44 ± 1.74	17.44 ± 2.03
	Week 8	19.23 ± 1.87	18.61 ± 2.07	18.12 ± 1.59
	Week 16	19.17 ± 1.10	19.09 ± 2.23	18.21 ± 1.63
	Post	19.75 ± 1.63	18.22 ± 2.14	18.61 ± 1.59
Agility (change in direction 180°) ^e	Pre	11.22 ± 1.37	10.55 ± 0.66	10.55 ± 0.77
	Week 8	11.32 ± 1.06	10.77 ± 1.06	10.15 ± 0.89
	Week 16	10.90 ± 1.02	10.60 ± 1.08	10.37 ± 0.90
	Post	10.52 ± 1.19*&	10.43 ± 1.11*&	10.03 ± 0.45*

^a**FBR**: push-up test; ^b**ABD** – 1-minute sit-up test; ^c**FLX** – sit and reach test; ^d**IL** – Illinois Agility Run; ^e**SHRN** – Shuttle Run. * Significant difference in relation to the Pre period; & Significant difference from week 8; £ Significant difference from week 16.

in the two types of jump (vertical and horizontal). Comparing the horizontal and vertical jumps, the former requires greater exertion of hip muscles(34), and there is evidence that ST, even when non-specific, can provide strength gain in hip muscles(35,36). Thus, it can be inferred that ST provided potential strength gain in the hips, which may have contributed to the significant gain in LL power in horizontal jump, although it does not explain why the same did not occur with the DUP group. This was probably due to the characteristic of the sample, for whom the movement involved in the horizontal jump was easier to learn compared to the vertical jump.

The lack of significant gain in LL power in vertical jump with ST, in all periodization models used, differs from the study that compared ST results using DUP and LP with 14 young male firefighters (21.9 ± 1.8 years)(37). The authors concluded that both periodization models provided LL power gain in vertical jump. The same occurred in another study, where the authors observed similar results with the use of WUP and LP models with 33 young men (20.0 ± 2.6 years) with experience in ST, with both ST periodization models also providing LL power gain in vertical jump(38). A possible explanation for the difference in the results of those studies and ours is the different jump protocols (Counter Movement Jump and Sargent Jump Test), since SJT is performed with the aid of the arms, unlike CMJ.

In this study, all periodization models provided gain in UL and abdominal endurance between the pre- and post-test periods, after 24 weeks of ST (Table 3). However, in the groups that trained with undulating models, significant gain in UL endurance occurred with shorter ST time, at week 16. In a study involving 60 volunteers, 30 men and 30 women, college students with experience in ST who performed ST for lower limbs with linear, reverse linear or DUP periodization, the authors found no significant difference in LME gain, measured by the number of knee extension repetitions using isokinetic dynamometry, in any of the groups after six weeks of training, only after 15 weeks(39). In a study with 28 young, sedentary women who underwent ST with linear periodization or

DUP, after 12 weeks of training the authors observed that both groups achieved LME gain in upper and lower limb repetition tests, and there was no significant difference between the groups(30). A possible explanation for the differences between the results of those studies and ours is that in both studies the ST program was specific for muscular endurance gain, consisting of series with 15, 20 or 25RM.

Previous studies suggest that ST can provide chronic effects of flexibility improvement (40–42). However, in this study no significant differences were found between the results in the pre and post ST periods with LP, WUP or DUP in the sit and reach flexibility test. A significant difference was found only in the WUP group between the results in the pre-test period and week 8. However, although there was no significant difference, the flexibility results in the WUP and DUP groups showed progressive gain at each test, pre-test, week 8, week 16 and post-test (Table 3), suggesting evidence of a possible advantage of ST with undulating periodization models over the linear model in flexibility gain. Studies that also measured flexibility after ST protocols through the sit and reach flexibility test found similar results, i.e., no gain in LP(43) and significant gain in undulating models(44). The benefits of ST in flexibility are possibly related to adaptations in the connective tissue and range of joint motion(45). There seems to be an advantage in undulating models over the traditional linear model(46), although the reasons are not well understood yet.

Regarding agility, ST had no effect on change of direction in movement, regardless of the periodization model. In addition, there was a significant loss in agility performance in sudden change of direction in LP and DUP. In LP there was a decline between the pre-test and relationship between agility and endurance of lower limbs(47). The findings of this study are in agreement with other studies that showed that strength gain provided by ST does not seem to be related to agility gain, regardless of the training volume(48) or whether the training routine involves only the lower limbs or the whole body(49). Nonetheless, there is evidence that long-term ST can provide gain in agility performance in an abrupt change of direction(50).

Study strengths and limitations

One of strengths of this study was its experimental and longitudinal design. While most of the previous studies identified examined ST periodization in training periods ranging from 8 to 16 weeks, in this study the intervention period was 24 weeks of ST, which affords greater robustness to the long-term effects of physical training.

Another point that emphasizes the relevance of this study is the scarcity of studies comparing ST programs using the three periodization models: LP, WUP and DUP, with most studies involving only two of the models. Thus, these results make an important contribution to fill the gap in existing knowledge on the subject.

Although there was an adaptation phase to the experimental protocol, a possible limitation of the study was the learning capacity of each volunteer, besides the individual motivation to undergo ST. The order of execution of the exercises was random, being performed according to the volunteer's choice.

Conclusion

The goal of this study was to analyze the effects of different models of linear, weekly undulating and daily undulating periodization for ST on submaximal strength, power, endurance, flexibility and agility in physical education students with no experience in ST.

It is concluded that, for inexperienced individuals, 24 weeks of ST will provide gain in different manifestations of strength, regardless of the periodization model (LP, WUP or DUP). Linear periodization and WUP seem to provide greater gain in horizontal jump, but ST provided no significant gain in vertical jump, regardless of periodization. All periodization models provided gain in muscular endurance, but such gain seemed to be faster in the undulating models. Simple undergoing ST does not seem to influence flexibility, and even appears to hinder agility, regardless of the periodization model adopted.

Therefore, we believe that professionals and researchers in physical education and other areas of health care can benefit from the results of this study regarding the selection of the best ST periodization model, according to the physical and motor valence to be developed.

Conflict of interests

There is no conflict of interest in this study.

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