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Effects of a Pilates programme in spinal curvatures and hamstring extensibility in adolescents with thoracic hyperkyphosis: a randomised controlled trial

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ABSTRACT
Aim To evaluate the effects of a 9-month Pilates exercise programme on the sagittal spinal posture and hamstring extensibility of adolescents with thoracic hyperkyphosis.
Design Randomised controlled trial with blinded examiner.
Patients One-hundred and three adolescents with thoracic hyperkyphosis.
Interventions Participants were randomly placed into an experimental group which participated in a Pilates exercise programme implemented for a total of 38 weeks (two sessions/week, 15 min/session) (Pilates group (PG), sample=49, or control group (CG), sample=48).
Main outcome measures The outcome measures were the thoracic curve in sagittal spinal curvature in relaxed standing, sagittal spinal curvatures and pelvic tilt in relaxed standing and sit-and-reach positions, and hamstring extensibility.
Results There was a significant adjusted mean difference between groups in favour of the PG in the thoracic curve in relaxed standing position (−5.6°, p=0.003), pelvic tilt (−2.9°, p=0.03) and all straight leg tests (p<0.001). The PG showed a significant change in thoracic curve (−5.9, p<0.001) and in lumbar angle (4.0, p=0.001) in relaxed standing position and in all straight leg raise tests (+6.4 to +15°, p<0.0001).
Conclusions The adolescents with thoracic hyperkyphosis from the PG had a decreased thoracic kyphosis in relaxed standing position, and improved hamstring extensibility as compared with the CG. More than 50% of the participants obtained kyphosis values inside normality, showing an adjusted mean difference between groups in the thoracic curve of about 73% of the baseline mean, resulting in a large improvement and high clinical importance.
Trial registration number NCT03831867.

INTRODUCTION
Deviations from the optimal spinal curvatures, such as thoracic hyperkyphosis, are a common problem observed in more than one in five adolescents[1 2] that can change the load distribution and increase intradiscal pressure[3] and viscoelastic deformation.[3–5] These factors are associated with a higher probability of developing different injuries, such as back pain,[6] spondylolisthesis, disc hernias or acute and chronic injuries in muscles, tendons and ligaments in the lower and upper extremities.[7]

Postures in which the curvatures of the spine exceed the limits of normality are considered as postures that could increase the intradiscal pressure and favour the possibility of spinal, muscle, tendon or ligament injuries.[7] This is even more important in children and adolescents, as their spinal structures are growing and are therefore more vulnerable.[8] In this respect, a lack of hamstring extensibility has been associated with a high thoracic curvature during trunk flexion.[9]

The Pilates method, one of the approaches that is currently used to promote a healthy sagittal spine,[10 11] has demonstrated positive effects in the adolescent population.[12] However, although some studies have found a reduction in the thoracic curve of adults after a Pilates programme,[13 14] no studies have been conducted with adolescents with or without hyperkyphosis. Therefore, the aim of this study was to evaluate the effects of a 9-month Pilates exercise programme on the sagittal spinal posture and hamstring extensibility of adolescents with thoracic hyperkyphosis.

METHODS
Study design
A 9-month (38 weeks) randomised controlled trial was conducted. The group assignment was blinded to the examiner and the staff who performed the statistical analysis. The trial design was registered with ClinicalTrial.gov and followed the Consolidated Standards of Reporting Trials guidelines.

Participants
This study was conducted at a school and sports science laboratory. A total of 103 students (13.48±1.23 years) were recruited from a high school located in the Region of Murcia (Spain) and were randomly placed into the Pilates group (PG, n=52) and control group (CG, n=51).

The inclusion criteria were (1) a thoracic hyperkyphosis (greater than 40°)[15] diagnosed by a medical doctor; (2) not being under a specific treatment for hyperkyphosis, scoliosis, or any spinal pathology; and (3) being physically active in physical education sessions. The exclusion criteria were having any neurological, cardiological, musculoskeletal or metabolic alterations that were different from thoracic hyperkyphosis.

Procedures
The PG performed two sessions (15 min) of a Pilates exercise programme for 38 weeks as a

Figure 1 Pilates method exercise.

replacement for the physical education school session. This duration was selected due to the length of the school year. The physical education teacher, who had a Pilates training certificate and more than 10 years of experience, was in charge of implementing the programme at the school. The programme was divided into three phases. Figure 1 describes the Pilates method exercise protocol. The Pilates exercise programme was developed following the indications of previous publications.[16] For each phase, an exercise focused on the rectus abdominis, an exercise focused on the oblique muscles, an exercise focused on the paravertebral muscles and a muscle stretching exercise were chosen. The exercises in phase I were less demanding, increasing the difficulty in phases II and III.

The CG students attended their two regular physical education sessions and did not participate in any specific or structured exercise programme that was different from their regular physical education lesson.

Assessment

All the measurements were performed in a single session between the hours of 09:30 and 14:00 by the same researchers. The sport science laboratory temperature was standardised at 24°C. No warm-up or stretching exercises were performed by the participants before the measurements,[17] and there was a 5 min rest between tests.

Figure 2 Spinal mouse.

Sagittal spinal curvature was assessed in relaxed standing and in sit-and-reach positions with a spinal mouse system (Idiag, Fehraltdorf, Switzerland) (figure 2). This instrument had a high intrarater (intraclass correlation coefficient (ICC) 0.61–0.96) and inter-rater (ICC 0.70–0.93) reliabilities. The spinal mouse was placed on the spinous process of T1 and moved caudally over the different spinous processes of the spine until it reached the beginning of the sacral area (S1). The spinal mouse software is standardised with Microsoft Office for the execution of the records and to present the differences in the physiological values of the curves according to sex and age.[18] Such software creates a precise configuration of the spine using a sophisticated algorithm. Assessment of posture and mobility is based on a series of measurements of the frontal and sagittal planes and the close connection between the surface of the back and the midline of the spine. The results shown are contrasted with previous reference values (Idiag M360, 2018).[19]

To assess hamstring extensibility, the passive and A-SLR and sit-and-reach tests were used. This test has been reported to have a high reliability (dominant ICC 0.93, non-dominant ICC 0.97).[20] Both tests were performed according to previously described protocols.[21] For passive straight leg raise (P-SLR), the participant was placed supine on the table, placing the lumbar support and the inclinometer at 0° in the initial position, which was the tibial tuberosity, and establishing the degrees of hip flexion at the end of it. The examiner then performed a slow and progressive flexion of the hip with the knee extended, taking the angular value of the maximum flexion that the individual tolerated or the moment at which the pelvis began to tilt in retroversion. An assistant kept the contralateral leg extended and in contact with the table, avoiding external rotation, as well as the rotation of the pelvis in its longitudinal axis. The procedure was the same for the active straight leg raise (A-SLR), except that in this case it was the participant who had to perform hip flexion without the help of the examiner.

For sit-and-reach test, each participant was examined in sportswear and without shoes, sitting on the examination table, with knees extended and feet hip-width apart, with ankles flexed at 90°. The soles of the feet were placed perpendicular to the ground, in contact with the measuring box, and the balls of the feet facing upward. In this position, the participant was asked to perform a maximum flexion of the trunk without bending the knees and keeping the arms extended, the palms of the hands one on top of the other, sliding on the box until reaching the maximum possible distance. During the test, one of the researchers took care that the soles of the feet remained fully supported on the surface of the box and that the knees were fully extended.

A simple randomisation method (Microsoft Excel V.2016) was used for the subjects distribution in PG and CG. Two groups were established according to thoracic hyperkyphosis, and then a randomised sequence was generated for these two groups by simple randomisation. Group assignment was blinded to the examiners and staff who performed the statistical analysis.

The sample size and power were determined via an analysis of previous research using the SD established for thoracic sagittal curvature spine by spinal mouse,[22] a significance level of $\alpha=0.05$ and an estimated error of 2.8°, reported as a mean error of the thoracic sagittal curvature spine by the spinal mouse.[19] A dropout rate of 20% was assumed based on previous investigations.[23] In a preplanned sample size estimate, 51 participants per group were required to detect a 2.8° difference between groups for the sagittal thoracic curve change with a 95% power, and at a 0.05 level of significance. A total of 97 students completed the trial (PG=49, CG=48). The final sample size in each group provided our study with 95% power to detect 2.6° of difference between groups. Rstudio V.3.15.0 software was used to establish the sample size.

Statistical analysis

After analysing the normality of the variables with the Kolmogorov-Smirnov test, the primary analysis performed was an analysis of covariance, which was used to compare the changes from the baseline between groups. Potential confounders were selected based on a previous study. Sex, age and baseline values were chosen as covariables.

The thoracic curvature in relaxed standing position with an thoracic angle higher than 40° was considered hyperkyphosis.[15] A multiple logistic regression was performed to analyse the responder of the primary outcome (OR and 95% CI). A secondary analysis was performed with the analysis of the responder. A response is defined as a final kyphosis of less than 40°. Baseline kyphosis, sex and age were included as covariables. To indicate the percentage of improvement, the degrees of improvement needed to define a thoracic curvature within normality were calculated (baseline thoracic curve of 40°) and was taken into account as a 100% improvement.

A two-way analysis of variance with repeated measures with one factor (time) was used to analyse within-group relationships.

All analyses were based on intention to treat with an error of $p\leq0.05$ established. The statistical analysis was performed using the statistical package SPSS 24.0 for Windows.

RESULTS

Characteristics of the sample

Ninety-four per cent of the PG and CG attended more than 95% of the session (sessions attended), and 94% and 94% of PG and CG, respectively, complied with the assessment (follow-up exam) (figure 3).

The PG (13.4±1.2 years) consisted of 37 (76%) women, and 12 (24%) men, and the CG (13.6±1.2 years) consisted of 34 women (71%) and 14 men (29%). As for the baseline, the PG and CG showed a thoracic angle in standing relaxing position of 47.9°±5.6° and 48.2°±5.7°, respectively.

Intragroup change

There was a significant reduction in the thoracic kyphosis angle and lumbar lordosis angle in the relaxed standing position for the PG. There was a significant increase in thoracic curve and pelvic tilt, and reduction of lumbar kyphosis in the sit-and-reach position for both the PG and CG. The PG showed a trend of

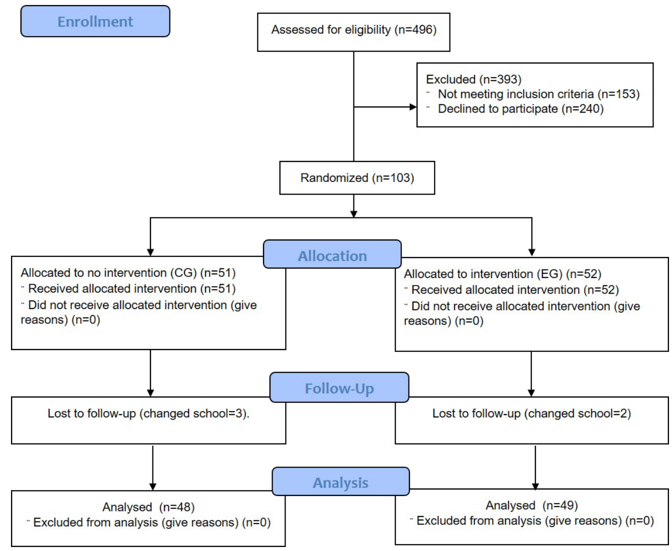

Figure 3 Consolidated Standards of Reporting Trials flow diagram. CG, control group; EG, experimental group.

significant improvement in the values achieved in the sit-and-reach, and a significant improvement in A-SLR (right and left) tests and P-SLR (right and left).

The CG had a tendency to significantly decrease its values in the A-SLR test (left leg) and to increase their values in the P-SLR test (right leg) (table 1).

Differences between groups

There were a significant difference in the adjusted mean difference between groups in the thoracic curve in the relaxed standing position (−5.6°, p=0.003) (primary analysis). The average of the variable degrees of improvement for obtaining a curve within normality was 8.1°. The adjusted mean difference between groups found for the thoracic curve was 5.9°, and in this case, this value represented 73.11% of the total. A final diagnosis of hyperkyphosis was shown in 53% (n=26) of the PG participants and in 77% (n=37) of the CG participants. The analysis of the responder demonstrated a stronger association with achieving a kyphosis of less than 40° with the PG (OR=6.488, 95% CI 2.123 to 19.825; p=0.001).

Adjusted mean differences were different between groups in pelvic tilt (−2.9; p=0.03), and in all the straight leg raise tests (from 8.4 to 11.3, all p<0.0001) (table 2).

Differences between groups in the change

There was a significant difference in thoracic curve in the relaxed standing position (p=0.003), in pelvic tilt (p=0.03), A-SLR (right and left) test (p<0.0001 for both), and P-SLR (right and left) test (p<0.0001 for both) (table 2).

In the PG, a final hyperkyphosis was shown by 53% (n=26) of the participants, and in the CG, this was observed in 77% (n=26) of the participants.

In connection with the intergroup change, there was a significant reduction in the thoracic kyphosis angle and lumbar lordosis angle in the relaxed standing position for the PG. There was a significant increase in thoracic curve and pelvic tilt, and a reduction of lumbar kyphosis in the sit-and-reach position for both the PG and CG. The PG showed a trend of significant improvement in the values achieved in the sit-and-reach and a significant improvement in the A-SLR (right and left) and P-SLR (right and left) tests.

Table 1 Differences between groups in the change pretest–post-test for sagittal spine curvature and hamstring extensibility (PG=49, CG=48)

Test	Group	Preintervention (mean±SD)	Postintervention (mean±SD)	Difference post-test–pretest (mean±SD)	P	95% CI (Mpost–Mpre)
Relaxed standing position						
Thoracic angle (degrees)	PG	47.9±5.6	42.00±9.4	−5.9±10.0	0.000	−8.6 to −3.0
	CG	48.2±5.7	45.9±8.2	−2.3±9.6	0.106	−5.1 to 0.5
Lumbar angle (degrees)	PG	−38.7±7.3	−34.8±6.5	4.0±7.4	0.001	1.5 to 5.9
	CG	−36.3±6.5	−34.4±6.5	1.8±8.3	0.105	−0.4 to 4.1
Pelvic tilt (degrees)	PG	25.2±6.6	23.4±6.0	−1.8±6.2	0.177	−4.2 to 0.8
	CG	21.4±6.6	21.4±6.4	−0.02±10.6	0.987	−2.5 to 2.5
Sit and reach position						
Thoracic angle (degrees)	PG	61.7±14.1	67.9±11.6	6.1±13.2	0.001	2.2 to 9.1
	CG	66.0±10.5	71.8±12.4	5.8±11.1	0.001	2.4 to 9.3
Lumbar angle (degrees)	PG	28.9±9.3	24.8±10.0	−4.7±9.8	0.001	−7.5 to −2.0
	CG	25.7±9.8	19.9±13.0	−5.8±9.5	0.000	−8.6 to −3.0
Pelvic tilt (degrees)	PG	−9.1±12.4	−4.4±13.2	4.7±11.0	0.001	2.006 to 7.6
	CG	−15.4±13.0	−9.0±14.1	6.4±8.3	0.000	3.6 to 9.2
Sit and reach score value (cm)	PG	−5.5±7.6	−4.1±8.9	1.4±4.2	0.058	−0.1 to 2.9
	CG	−10.1±8.9	−9.19±8.54	.9±5.9	0.207	−0.5 to 2.4
A-SLR						
Right (degrees)	PG	70.8±12.6	77.4±16.6	6.4±11.7	0.000	3.4 to 9.5
	CG	67.4±15.2	66.2±10.4	−1.4±9.4	0.458	−4.2 to 1.9
Left (degrees)	PG	69.5±11.1	77.7±16.9	7.9±13.2	0.000	4.2 to 11.6
	CG	67.8±13.3	64.3±11.3	−3.5±12.3	0.062	−7.1 to 0.2
P-SLR						
Right (degrees)	PG	83.3±13.8	98.5±19.6	15.0±12.2	0.000	12.2 to 17.8
	CG	84.0±15.4	88.0±12.9	3.9±6.5	0.006	1.1 to 6.7
Left (degrees)	PG	80.7±12.3	95.7±16.6	14.6±13.5	0.000	11.3 to 17.8
	CG	81.8±14.7	84.0±11.7	2.2±8.9	0.197	−1.1 to 5.4

A-SLR, active straight leg raise; CG, control group; Mpost–Mpre, mean post-test minus mean pretest; PG, Pilates group; P-SLR, passive straight leg raise.

The CG had a tendency to significantly decreased value in the A-SLR test (left leg) and increased value in the P-SLR test (right leg) (table 1).

With respect to safety, there were adverse events in both groups, PG and CG. One for PG and two for CG were lost to follow-up due to foot surgery, ankle sprain and knee injury. These adverse events did not occur during the exercise intervention.

DISCUSSION

The aim of this study was to evaluate the effects of a 9-month Pilates exercise programme on the sagittal spinal posture and hamstring extensibility of adolescents with thoracic hyperkyphosis. The main finding of the present study was that the PG improved its thoracic kyphosis in relaxed standing position after a 9-month Pilates programme; the CG did not show differences, and signficant differenes were found between the groups. In addition, at the end of the programme, there were significantly less participants with hyperkyphosis in the PG than in the CG. As for the clinical difference, the adjusted mean difference between groups was about 73%, considered a high value with clinical relevance. The participants who practiced Pilates reached a thoracic curve angle that was nearly normal (42°) and achieved average values that were less close to the upper limit of lumbar curvature. A normal angle for thoracic[15] and lumbar[24] curvatures is considered to be less than 40°. Concerning the lumbar lordosis angle, there were no differences between groups in the changes observed, although the PG reduced the lordosis curvature significantly.

These findings are in line with those from other studies which implemented a Pilates method programme for adult women with hyperkyphosis[14] and older adults without hyperkyphosis.[13] These authors implemented Pilates programmes that lasted 10–30 weeks, twice or three times per week, 75 or 60 min/session, respectively.[13 14] Both showed reductions in the thoracic curvature[13 14] and lumbar curvature.[13] Nevertheless, despite the fact that no studies were found which asessed the effect of a Pilates programme on the sagittal spinal curvature of adolescents with or without hyperkyphosis, two studies were found that performed a systematic exercise programme with boys who had hyperkyphosis and hyperlordosis,[25] or girls with hyperlordosis.[26] These exercise programmes consisted in performing stretching and strengthening exercises, 3 days/week, 60 min/session, for 8 weeks. After the intervention, thoracic[25] and lumbar curvatures significantly decreased,[26] and our results are in line with this study. Yazici and Mohammadi[25] reported a decrease of 3.81° of kyphosis and Fatemi *et al*[26] noted 6.10° of reduction in the lumbar curvature. The improvement of the present study is about 5.9° and 4.0°, respectively. This could be because the exercises performed within the Pilates method also focus on strengthening the core musculature and stretching the tonic musculature[27 28] parameters that have been shown to influence the sagittal arrangement of the spine.[29] So it can be seen that both the strengthening and flexibility exercise programme and a Pilates programme achieve improvements on thoracic kyphosis; however, we cannot establish comparisons because the duration of the session, the weekly frequency and the time of the applied

Table 2 Differences pretest to post-test (intragroups) for sagittal spine curvatures and hamstring extensibility (PG=49; CG=48)

Test	Group	Difference post-test–pretest (mean±SD)	Adjusted mean difference EG–CG	95% CI	P value (adjusted by sex, age and outcome baseline)
Relaxed standing position					
Thoracic angle (degrees)	PG	−5.9±9.9	−5.6	−9.4 to −2.0	0.003
	CG	−2.3±9.6			
Lumbar angle (degrees)	PG	4.0±7.4	−0.1	−2.7 to 2.5	0.945
	CG	1.8±8.2			
Pelvic tilt (degrees)	PG	−1.8±6.2	−2.9	0.3 to 5.4	0.030
	CG	−0.02±10.6			
Sit and reach position					
Thoracic angle (degrees)	PG	6.2±13.2	2.5	−2.0 to 7.0	0.272
	CG	5.8±11.1			
Lumbar angle (degrees)	PG	−4.7±9.8	−2.7	−6.6 to 1.2	0.174
	CG	−5.8±9.5			
Pelvic tilt (degrees)	PG	4.7±11.0	−1.1	−5.0 to 2.8	0.572
	CG	6.4±8.3			
Sit and reach (cm)	PG	1.4±4.2	1.5	−0.8 to 3.7	0.203
	CG	.9±5.9			
A-SLR					
Right (degrees)	PG	6.4±11.7	8.4	4.2 to 12.7	0.000
	CG	−1.2±9.4			
Left (degrees)	PG	7.9±13.2	11.3	6.1 to 16.5	0.000
	CG	−3.5±12.3			
P-SLR					
Right (degrees)	PG	15.0±12.2	10.1	6.0 to 14.2	0.000
	CG	3.9±6.5			
Left (degrees)	PG	14.6±13.5	11.8	7.1 to 16.4	0.000
	CG	2.2±9.0			

A-SLR, active straight leg raise; CG, control group; PG, experimental group; P-SLR, passive straight leg raise.

programme were different between the present and previous studies. An investigation comparing different types of strengthening and stretching programmes and pilates programmes is necessary to be able to establish comparisons. It is considered necessary to be able to investigate which programme is most effective for this objective. Aside from the aforementioned studies,[13 14 25] another five studies were found that investigated the effect of a specific exercise programme on spinal sagittal curvature in individuals with hyperkyphosis.[15 30] Four of them showed differences in the changes between groups,[15] and one of them did no indicate a difference.[30] All of these studies showed a reduction in the kyphosis thoracic angle,[30] approaching the values considered to be normal for the thoracic curvature, as in the present study.

In this sense, it was shown that practising an exercise programme that included stretching and strengthening exercises, such as a Pilates method, could reduce the thoracic and lumbar curvatures of adolescents with hyperkyphosis. Our finding confirms the association established between the Pilates method and the stability of the spine, hamstring extensibility and trunk strength in adolescents,[12] the fitness factors associated with spine misalignment,[31] suggesting that the Pilates method could promote a healthier sagittal spinal disposition.

The PG and the CG obtained significantly higher thoracic kyphosis curvatures, lower lumbar curvatures and pelvic tilts in the sit-and-reach position after 9 months, without differences between groups. In this sense, the same changes have been found in same-age non-athlete adolescents,[32] while another study reported on a similar change for the CG after 6 months.[24] This could suggest that despite the Pilates method for improving sagittal spinal curvature in standing relaxed position, these changes have yet to be transferred to the spinal dynamics in the trunk flexed position. This could be because the amount of Pilates practised in the present investigation did not compensate for the changes induced by the growing processes on this positions. However, a small protective effect of the increase of the thoracic curve is suggested, because the power of the effect was smaller for the PG than the CG. On the other hand, several authors showed the existence of a connection between sagittal spinal curvature in trunk flexion with knees extended and hamstring extensibility.[9 22] A previous study found a significant improvement of thoracic curve and pelvic tilt in a similar position (toe-touch position) in women after a stretching exercise programme, showing an improvement in hamstring extensibility in the toe-touch test, in agreement with the improvement in the sit-and-reach test of the PG in the present study.[22] It is possible that the Pilates method programme implemented in this study improved hamstring extensibility, but this improvement was not enough to influence the sagittal spinal curvature in trunk flexion with knees extended due to the low stretching load; three of the four exercises focused on trunk strengthening and only one focused on stretching. This was enough to improve sagittal spinal misalignment in the standing position, although it was insufficient for sagittal spinal curvatures in the trunk flexion position. Future studies should assess the effect of a different exercise distribution or training loads.

In light of the aforementioned points, this fitness factor is with sagittal spinal curvature. Thus, Pilates method programmes have been shown to induce improvements in adolescents without hyperkyphosis as inclusion criteria[12] or adolescents with back pain.[33] Therefore, a study that assesses this effect on adolescents with hyperkyphosis is necessary.

The changes in the hamstring extensibility measured with the straight leg raise were significantly different between groups. The PG showed a significant improvement in the straight leg raise tests after a 9-month Pilates method programme. In connection with the clinical difference, these participants shifted from a short hamstring to normal hamstring extensibility in the right and left A-SLR tests[24] and in the P-SLR test.[34] This finding broadly supports others studies with adolescent subjects without thoracic hyperkyphosis as an inclusion criteria.[12 28] Improvements were shown in hamstring extensibility after a Pilates programme lasting 60 min/session, two sessions per week for 6 weeks[28]; although differences in the change between groups were not observed.[12]

Others studies found significant improvements after a specific hamstring extensibility programme for adolescents without hyperkyphosis as an inclusion criteria (programme lasting from 5 to 9 weeks, two sessions per week, 3–6 min per session).[35] In addition, a difference in the change between groups was indicated.[35] These results contribute new knowledge about the effect of the Pilates method on hamstring extensibility of adolescents with thoracic hyperkyphosis. The hamstring has been described as being important for thoracic hyperkyphosis,[9] as an improvement in hamstring extensibility has been linked with a reduction in the thoracic kyphosis angle. In addition, the other fitness factor related to thoracic kyphosis is the lack of abdominal and paravertebral strengthening.[31] Some research studies have described a positive effect of the Pilates method on this fitness factor in adolescents.[12] Therefore, the Pilates method could be a more valid, specific and suitable method for preventing or reducing thoracic hyperkyphosis as compared with a specific stretching-based programme.

The selected Pilates exercises present similarities to those previously included in studies with adolescents with hyperkyphosis and hyperlordosis.[25 26] Although some exercise could be considered to adopt positions of hyperkyphosis and could favour it, the result of their practice has not led to a worsening of the curvature neither in this nor in previous investigations. In contrast, an improvement in this curvature has been produced. This could be due to the improvement produced in the flexibility of the hamstring muscles. Greater hamstring extensibility is associated with greater pelvic tilt and lumbar flexion, as well as less thoracic kyphosis.[9 36] In addition, the selected exercises have been shown to improve the strength and resistance of the trunk and paravertebral muscles,[27 28] parameters that influence the sagittal position of the spine.[29] A different selection of exercises should be investigated.

Our study is not without limitations. The non-blinding of the participants affected the internal validity, but the main strength of this study was the viability of the exercise programme. Although other research studies implemented efficient exercise programmes for thoracic hyperkyphosis, these programmes had several limitations, such as the subjects performing sessions lasting 60[14 25] or 75 min/session,[13] for 8,[25] 10[13] or 30 weeks.[14] These programmes are not viable for physical education classes, as many different topics are discussed during class. Thus, the teachers cannot use the entire class time for only one topic, with the time spent on each topic normally lasting 3–5 weeks. One solution could be to implement a programme that lasts 60 min/session for less than 6 weeks, but no studies were found that analysed the effect of programmes of this duration on thoracic hyperkyphosis. The detraining effects were not assessed, and therefore the durability of the effect of the Pilates programme is unknown. More research that evaluates the effect of detraining could be of interest to ensure the time and frequency necessary for implementing the programme. Therefore, the present programme is more viable as it used only a short part of the lesson during the academic year, so that the rest of the class session could be used to work on other topics. Furthermore, the present study did not include a group that performed classical core strengthening and stretching training to compare its effects with the group that performed Pilates-based exercises. This would be of interest in the future to determine which type of intervention is more effective in reducing thoracic hyperkyphosis in adolescents. Finally, the selection of exercises followed the same content structure used in previous research. However, there are no studies that have analysed the acute effects of performing a particular exercise of those classically used in the Pilates method on the sagittal arrangement of the spine. This is an interesting line of future research.

CONCLUSIONS

In conclusion, a 9-month Pilates exercise programme decreased thoracic kyphosis in relaxed standing position and improved hamstring extensibility of adolescents with thoracic hyperkyphosis, with more than 50% of the participants obtaining kyphosis values inside of normality, showing a 71% improvement from baseline values. This finding suggests that the Pilates method could be a suitable, effective and clinically relevant programme for a healthy sagittal spine curvature of adolescents with hyperkyphosis, showing a large and expected improvement. More research is needed to assess the effect of detraining.

Main messages

- The present study is carried out in an adolescent population diagnosed with hypokyphosis.
- There is no record of articles made with a population with the same characteristics.
- A 9-month Pilates intervention appears to be effective in decreasing thoracic kyphosis in relaxed standing and improving hamstring extensibility in adolescents with thoracic hyperkyphosis.andSpinal curvature deviations affect more than one in five adolescent populations.
- Deviations of the curvatures of the spine can be the cause of the development of back pain and injuries.

Current research questions

- The Pilates method seems to be a useful tool to prevent and improve spinal problems.
- What would be the most beneficial frequency, duration and type of physical activity to prevent or improve kyphosis in adolescents?

What is already known about the topic

- A physical exercise program for trunk strengthening and flexibility improves and prevents hyperkyphosis in adolescents.

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REFERENCES

1 González-Gálvez N, Vaquero-Cristóbal R, López-Vivancos A, *et al*. Back pain related with age, anthropometric variables, sagittal spinal curvatures, hamstring extensibility, physical activity and health related quality of life in male and female high school students. *Int J Environ Res Public Health* 2020;17:7293.

2 Brito-Hernández L, Espinoza-Navarro O, Díaz-Gamboa J. Postural evaluation and prevalence of Hyperkyphosis and Hyperlordosis in students of elementary school. *International Journal of Morphology* 2018;36:290–6.

3 Wilke HJ, Neef P, Caimi M, *et al*. New in vivo measurements of pressures in the intervertebral disc in daily life. *Spine* 1999;24:755–62.
4 Solomonow M, Zhou B-H, Baratta RV, *et al*. Biomechanics and electromyography of a cumulative lumbar disorder: response to static flexion. *Clin Biomech* 2003;18:890–8.
5 Batistão MV, Moreira RdeFC, Coury HJCG, *et al*. Prevalence of postural deviations and associated factors in children and adolescents: a cross-sectional study. *Fisioterapia em Movimento* 2016;29:777–86.
6 Diebo BG, Varghese JJ, Lafage R, *et al*. Sagittal alignment of the spine: what do you need to know? *Clin Neurol Neurosurg* 2015;139:295–301.
7 McGill SM. *Low back disorders: evidence-based prevention and rehabilitation*. Champaign: Human Kinetics, 2002.
8 Swärd L. The thoracolumbar spine in young elite athletes. *Sports Medicine* 1992;13:357–64.
9 Muyor JM, Vaquero-Cristóbal R, Alacid F, *et al*. Criterion-related validity of sit-and-reach and toe-touch tests as a measure of hamstring extensibility in athletes. *J Strength Cond Res* 2014;28:546–55.
10 Vaquero-Cristóbal R, López-Miñarro PA, Alacid Cárceles F, *et al*. [THE EFFECTS OF THE PILATES METHOD ON HAMSTRING EXTENSIBILITY, PELVIC TILT AND TRUNK FLEXION]. *Nutr Hosp* 2015;32:1967–86.
11 Cruz-Díaz D, Romeu M, Velasco-González C, *et al*. The effectiveness of 12 weeks of Pilates intervention on disability, pain and kinesiophobia in patients with chronic low back pain: a randomized controlled trial. *Clin Rehabil* 2018;32:1249–57.
12 González-Gálvez N, Poyatos MC, Marcos-Pardo PJ, *et al*. Pilates training induces changes in the trunk musculature of adolescents. *Revista Brasileira de Medicina do Esporte* 2019;25:235–9.10.1590/1517-869220192503163535
13 Kuo Y-L, Tully EA, Galea MP. Sagittal spinal posture after Pilates-based exercise in healthy older adults. *Spine* 2009;34:1046–51.
14 Junges S, Dias R, Sartori J. Change in pressure expiratory with the use of the method Pilates in adult women with hyperkyphosis. *Fisioterapia Brasil* 2017;18:643–9.
15 Jang HJ, Hughes LC, DW O. Effects of corrective exercise for thoracic Hyperkyphosis on posture, balance, and well-being in older women. *Journal of Geriatric Physical Therapy* 2017;13:1.
16 González-Gálvez N, Vaquero-Cristóbal R, Marcos-Pardo PJ. Effect of Pilates method on muscular trunk endurance and hamstring extensibility in adolescents during twelve weeks training and detraining. *J Bodyw Mov Ther* 2020;24:11–17.
17 Díaz-Soler MA, Vaquero-Cristóbal R, Espejo-Antúnez L, *et al*. [The effect of a warm-up protocol on the sit-and-reach test score in adolescent students]. *Nutr Hosp* 2015;31:2618–23.
18 Ramova EP, Poposka A, Lazovic M. School screening for bad posture with spine mouse device. *Macedonian Journal of Medical Sciences* 2010;1:1–6.
19 Kellis E, Adamou G, Tzilios G, *et al*. Reliability of spinal range of motion in healthy boys using a skin-surface device. *J Manipulative Physiol Ther* 2008;31:570–6.
20 Neto T, Jacobsohn L, Carita AI, *et al*. Reliability of the Active-Knee-Extension and Straight-Leg-Raise tests in subjects with flexibility deficits. *J Sport Rehabil* 2015;24:2014–220.
21 Ayala F, Sainz de Baranda P, De Ste Croix M, *et al*. Criterion-related validity of four clinical tests used to measure hamstring flexibility in professional futsal players. *Phys Ther Sport* 2011;12:175–81.
22 Muyor JM, López-Miñarro PA, Casimiro AJ. Effect of stretching program in an industrial workplace on hamstring flexibility and sagittal spinal posture of adult women workers: a randomized controlled trial. *J Back Musculoskelet Rehabil* 2012;25:161–9.
23 Miyamoto GC, Moura KF, Franco YRdosS, *et al*. Effectiveness and cost-effectiveness of different Weekly frequencies of Pilates for chronic low back pain: randomized controlled trial. *Phys Ther* 2016;96:382–9.
24 Santonja F. *Efectos de un programa de educación postural sobre El morfotipo sagital del raquis Y La extensibilidad isquiosural: estudio multicéntrico en escolares de Educación Primaria*. Proyecto de investigación, 2017.
25 Yazici AG, Mohammadi M. The effect of corrective exercises on the thoracic kyphosis and lumbar lordosis of boy students. *Turkish Journal of Sport and Exercise* 2017;19:177–81.
26 Fatemi R, Javid M, Najafabadi EM. Effects of William training on lumbosacral muscles function, lumbar curve and pain. *J Back Musculoskelet Rehabil* 2015;28:591–7.
27 González-Gálvez C-PM, Marcos-Pardo PJ, *et al*. The Effect of Pilates Method in Scholar's Trunk Strength and Hamstring Flexibility: Gender Differences. *International Journal of Medical, Health, Pharmaceutical and Biomedical Engineering* 2014;8:348–51.
28 González-Gálvez N, Poyatos MC, Pardo PJM, *et al*. Effects of a Pilates school program on hamstrings flexibility of adolescents. *Revista Brasileira de Medicina do Esporte* 2015;21:302–7.
29 González-Gálvez N, Gea-García GM, Marcos-Pardo PJ. Effects of exercise programs on kyphosis and lordosis angle: a systematic review and meta-analysis. *PLoS One* 2019;14:e0216180.
30 Kamali F, Shirazi SA, Ebrahimi S, *et al*. Comparison of manual therapy and exercise therapy for postural hyperkyphosis: a randomized clinical trial. *Physiother Theory Pract* 2016;32:92–7.
31 Czaprowski D, Stoliński Łukasz, Tyrakowski M, *et al*. Non-Structural misalignments of body posture in the sagittal plane. *Scoliosis Spinal Disord* 2018;13:1–14.
32 Conesa E. *Valoración de la Movilidad de la Columna en El Plano Sagital Y Extensibilidad de la Musculatura Isquiosural en Gimnasia Estética de Grupo*, 2015.
33 González-Gálvez N, Marcos-Pardo PJ, Carrasco-Poyatos M. Functional improvements after a Pilates program in adolescents with a history of back pain: a randomised controlled trial. *Complement Ther Clin Pract* 2019;35:1–7.
34 Li Y, McClure PW, Pratt N. The effect of hamstring muscle stretching on standing posture and on lumbar and hip motions during forward bending. *Phys Ther* 1996;76:836–45. discussion 845-9.
35 Mayorga-Vega D, Merino-Marban R, Vera-Estrada F. Effect of a short-term physical Education-Based flexibility program on hamstring and lumbar extensibility and its posterior reduction in primary school children. *Kinesiology* 2014;46:227–33.
36 Vaquero Cristóbal R, Esparza-Ros F, Gómez-Durán R. Thoracic and lumbar morphology in standing, sitting and maximal trunk flexion with extended knees in dancers. *Archivos de Medicina del Deporte* 2015;32:87–93.