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# The Relationship Between Hamstring Muscle Extensibility and Spinal Postures Varies With the Degree of Knee Extension

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The aim was to determine the relationship between hamstring muscle extensibility and sagittal spinal curvatures and pelvic tilt in cyclists while adopting several postures. A total of 75 male cyclists were recruited for this study (34.79 ± 9.46 years). Thoracic and lumbar spine and pelvic tilt were randomly measured using a Spinal Mouse. Hamstring muscle extensibility was determined in both legs by a passive knee extension test. Low relationships were found between hamstring muscle extensibility and spinal parameters (thoracic and lumbar curvature, and pelvic tilt) in standing, slumped sitting, and on the bicycle ($r = .19$; $P > .05$). Significant but low relationships were found in maximal trunk flexion with knees flexed ($r = .29$; $P < .05$). In addition, in the sit-and-reach test, low and statistically significant relationships were found between hamstring muscle extensibility for thoracic spine ($r = -.23$; $P = .01$) and ($r = .37$; $P = .001$) for pelvic tilt. In conclusion, hamstring muscle extensibility has a significant relationship in maximal trunk flexion postures with knees flexed and extended, but there are no relationships while standing or on the bicycle postures.

***Keywords:*** spinal curvatures, injury, flexibility, sit-and-reach, cycling.

Sagittal spinal morphology is characterized by several physiological curvatures (cervical lordosis, thoracic kyphosis, lumbar lordosis) and a sacral structure. An optimal alignment of spinal structures and joints is needed to assume standing posture with minimal muscular expenditure and spinal forces.[1] On the contrary, modifications in neutral sagittal spinal curvatures increase intervertebral stress,[2] viscoelastic deformation of lumbar tissues,[3] and thoracic and lumbar intradiscal pressure,[4] and all these factors might be relevant to predispose to spinal disorders.[5] Changes in body alignment (static posture) and alteration during movements (dynamic posture) have been considered common risk factors for lower back pain.[6] Furthermore, back pain has been associated with prolonged periods of static trunk flexion and decreased hamstring muscle extensibility[7] and changes in lumbopelvic rhythm.[8] In this sense, several studies have analyzed the influence of sports training on the sagittal spinal curvatures.[9–11,] Other studies have made comparisons among several sports disciplines or sports categories and spinal adaptations.[12,13] Wojtys et al[13] found a proportional increase in thoracic kyphosis in relation to training volume per year. Recently, in cycling, Muyor et al.[11,12] found greater standing thoracic kyphosis in cyclists who have a high training volume, although they showed lower thoracic kyphosis on the bicycle than in standing. Some studies have shown that sports involving prolonged trunk flexion postures are associated with greater thoracic kyphosis.[9,10,13] However, there are few studies that have analyzed the correlation between sagittal spinal curvatures and hamstring muscle extensibility in athletes.

Clinical observations suggest that hamstring muscle extensibility may be associated to specific pelvic and trunk postures.[14] Since the hamstring muscles originate on the ischial tuberosity of the pelvis, a reduced extensibility will influence the range of motion and position of the pelvis.[15,16] Reduced hamstring muscle extensibility decreases the pelvic flexion range of motion during forward bending postures with the knees straight.[17] In a nonathlete population, Toppenberg and Bullock[18] found that hamstring muscle extensibility was significantly and negatively correlated to the lumbar lordosis in a standing posture. Li et al[19] reported that there were no differences between hamstring muscle extensibility and lumbopelvic posture in a standing posture. Furthermore, they indicated that decreased hamstring muscle length was associated to greater relative lumbar motion during forward bending.

McCarthy and Betz[20] reported a significant correlation between tight hamstrings, as measured by the popliteal angle, and decreasing lumbar lordosis, especially

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when sitting in children with cerebral palsy. Norris and Matthews[21] did not find any association between hamstring muscle extensibility and total angle pelvic tilt in people with extensibility of the hamstrings within normal limits. However, in this study the subjects did not reach maximal trunk flexion in the postures analyzed. Recently, Bellew et al[22] reported that the hamstring muscles influence pelvic rotation during forward bending in healthy individuals.

Many sports disciplines require repetitive movements or a predominance of trunk flexion postures which could be affected by hamstring muscle extensibility. Studying young athletes, López-Miñarro and Alacid[23] found that hamstring muscle extensibility influences the thoracic and pelvic postures when maximal trunk flexion was performed. In highly trained young kayakers, López-Miñarro et al[24] found that lower hamstring extensibility is related to increased spinal flexion and posterior pelvic tilt when sitting in the boat. Specifically, in cyclists, McEvoy et al[25] observed greater anterior pelvic tilt in comparison with sedentary subjects during sitting on the floor with extended knees. However, none of these studies analyzed the relationship between hamstring muscle extensibility and the sagittal spinal curvatures in those athletes´ daily postures.

Many of the functions that occur either during work or everyday activities require trunk flexion.[19] The cyclist's specific posture riding on the bicycle is trunk flexion to keep the upper body segments on the handlebar.[10–12] Recently, Muyor et al[26] found that hamstring muscle extensibility does not influence the thoracic, lumbar and pelvic postures when cyclists are seated on their bicycles. However, in that study, the sample was divided into two groups with regards to their hamstring muscle extensibility, so that the results could have been altered, if this study had taken place without dichotomization based on hamstring extensibility. In that study, the test used was the passive straight leg raise.

On the other hand, the sit-and-reach test (maximal trunk flexion with knees extended) is commonly performed by cyclists as a stretching exercise for the hamstring muscle before and after the training in cycling. Recently, Muyor et al found that cyclists showed greater lumbar flexion in maximal trunk flexion with knees extended that sedentary people, but the authors did not study the relation between the spinal posture adopted and hamstring muscle extensibility.

The hypothesis in the current study is that the hamstring muscle extensibility influences spinal curvatures and pelvic tilt when maximal trunk flexion postures with knee extended are reached because, in this position, the hamstring muscles are tensed. However, the relationships may not be strong because cyclists have spinal adaptations to maintain flexion posture on the bicycle. Since cyclists frequently adopt flexion postures in daily activities, in stretching exercises and on their bicycles, because the hamstring muscle extensibility appears to influence the spinal curvatures and because flexion postures have been associated with possible spinal injuries,[4,5] the main purpose of this study is to determine the relationships between hamstring muscle extensibility and the sagittal spinal curvatures and pelvic tilt in cyclists during different postures, and while on their own bicycles.

# Methods

## Subjects

A total of 75 male cyclists were recruited for this study. Sample characteristics are summarized in (Table 1). Cyclists were excluded if they presented pain induced or exacerbated by the testing procedures, injury or lower back pain preventing participation in cycling training before testing, or known structural spinal pathology such as scoliosis, spondylolysis or spondylolisthesis, and if they showed 90° in both legs when the passive knee extension test was performed.

## Procedures

An Institutional Ethics Committee approved the study and all subjects signed a consent form before participation. Hamstring muscle extensibility was determined in both legs using the passive knee extension test. Sagittal thoracic and lumbar curvatures and pelvic tilt were measured using a Spinal Mouse system (Idiag, Fehraltdorf, Switzerland), in the standing position, slumped sitting, sitting with maximal trunk flexion, and maximal trunk flexion with knees extended (sit-and-reach test) and on their own bicycles with lower handlebar-hands position.

The Spinal Mouse was guided along the midline of the spine. Two rolling wheels follow the contour of the spine, and the angle measures are communicated from the device to a base station positioned approximately 1–2m away and interfaced to a personal computer. Data are sampled every 1.3 mm as the mouse is rolled along the spine, giving a sampling frequency of approximately 150 Hz. The average total length of the spine is 550 mm and the time required to measure the whole length is 2–4 s; thus, approximately 423 measurements are made over 3 s. This information is then used to calculate the relative positions of the sacrum and vertebral bodies of the underlying bony spinal column using an intelligent, recursive algorithm.[27] For global spinal angles, the Spinal Mouse has proved to be a valid and reliable device.[28,29]

**Table 1 Descriptive characteristics of cyclists, mean (SD)**

| Variable | Values |
|---|---|
| Age (y) | 34.79 (9.46) |
| Height (m) | 1.76 (.60) |
| Body weight (kg) | 76.44 (8.09) |
| Units in body mass index | 24.73 (.01) |
| Years of training experience (y) | 8.89 (7.64) |

The measurements were taken in a randomized order in a single session. No warm-up or stretching exercises were performed by the subjects before the test measurements. The subjects were allowed to rest briefly standing up for 5 minutes between measurements. Each subject was evaluated barefoot and wearing underwear. The laboratory temperature was standardized at 24°C.

Before taking measurements, the main researcher determined the position/location of the spinous process C7 (starting point) and the top of the anal crease (end point) by palpation and marked the skin surface with a pencil. The Spinal Mouse was guided along the midline of the spine (or slightly paravertebrally in particularly thin individuals with prominent processus spinous) starting at the processus spinous of C7 and finishing at the top of the anal crease (approximately S3). For each testing position, the angle of the thoracic (T1-2 to T11-12) and lumbar (T12-L1 to the sacrum) spine and the inclination of the pelvis (difference between the sacral angle and the vertical one) were recorded. In the lumbar curve negative values corresponded to lumbar lordosis (posterior concavity) and positive values corresponded to lumbar kyphosis or lumbar inverted (posterior convexity) (Table 2). With respect to the pelvic position, a value of 0° represented the vertical position. Thus, a greater angle reflected an anterior pelvic tilt and a lower angle (negative values) reflected a posterior pelvic tilt (Table 2). Each measurement was repeated twice within a 20 s rest. The average of the two trials was used for data analysis.

## Measures

***Standing.*** The cyclists, who were barefoot and wearing a culotte, assumed a straight position standing on the floor with their eyes and ears in a horizontal line, arms relaxed at the side of the body, knees close to individual full extension, and feet shoulder-width apart.

***Slumped Sitting.*** Subjects were instructed to sit on a chair without back support, with their hips and knees at a 90° angle and with their feet positioned shoulder width apart, and arms relaxed at the side of their body and hands on their thighs.

**Table 2 Descriptive data of measurements, mean (SD)**

| Variables | Mean |
|---|---|
| Hamstring muscle extensibility (°) | |
| Passive Knee Extension Test | 77.13 (7.37) |
| Standing (°) | |
| Thoracic spine | 45.99 (9.10) |
| Lumbar spine | –24.29 (8.00)* |
| Pelvic tilt | 10.76 (6,14) |
| Sitting (°) | |
| Thoracic spine | 45.34 (9.28) |
| Lumbar spine | 18.38 (11.05) |
| Pelvic tilt | –16.20 (8.88)† |
| Maximal trunk flexion while sitting with knees flexed (°) | |
| Thoracic spine | 65.23 (8.33) |
| Lumbar spine | 32.36 (9.25) |
| Pelvic tilt | 42.99 (9.45) |
| Sit-and-reach test (°) | |
| Thoracic spine | 62.49 (8.54) |
| Lumbar spine | 30.41 (9.19) |
| Pelvic tilt | –15.63 (8.55)† |
| On the bicycle in lower handlebar-hand positions (°) | |
| Thoracic spine | 40.53 (10.08) |
| Lumbar spine | 25.29 (8.77) |
| Pelvic tilt | 34.24 (6.97) |

*Negative values correspond to lumbar lordosis (posterior concavity) curvature.

†Negative values correspond to posterior pelvic tilt.

***Maximal Trunk Flexion While Sitting with Knees Flexed.*** While sitting on a chair with both knees flexed at a 100° angle, subjects were asked to slowly bend the trunk as far as possible, aiming to curl their head onto their knees.

***Maximal Trunk Flexion While Sitting with Knees Extended (Sit-and-Reach Test).*** Subjects were required to sit with their knees straight and legs together, so that the soles of their feet were flat against the end of a constructed sit-and-reach box (height = 32 cm). With palms down, subjects placed one hand on top of the other and slowly reached forward as far as possible. Subjects slid their hands along the box, with their knees extended (it was controlled by a second examiner), and held the resulting position for approximately 5 seconds while the spinal curvatures were measured.

***Sitting on the Bicycle in Lower Handlebar-Hands Position:*** Cyclists wore their own culotte and cycling shoes. They used their own bicycle. The subjects sat and pedalled for five minutes (to have time to adopt his usual position on the bicycle) at a cadence of 90 revolutions per minute (measured by a cadence meter) in a cycling trainer (CycleOps PowerBeam, USA). The cycle resistance was controlled with Borg's 6–20 points RPE scale. Each cyclist pedaled at "moderate intensity" (12–13 points). After five minutes the cyclists were asked to stop pedaling, and to maintain both pedals parallel to the floor. At this moment the tester measured the spinal angles and pelvic tilt. There was a 30 s rest period after each hand position measurement.

***Hamstring Muscle Extensibility.*** Hamstring muscle extensibility was determined by performing the passive knee extension test on each leg in counterbalanced order. The popliteal angle was measured with the cyclist supine on the examining table and the opposite hip fully extended, maintained by a Velcro strap secured to the table. The hip was flexed 90° (as measured by the angle subtended by a line from the greater trochanter to the center of the femoral condyle and the horizontal plane). In this position, a uni-level inclinometer (Isomed, Inc., Portland, OR) was placed over the distal tibia and the knee was passively extended by the tester until moderate resistance was felt or the subjects reported pain in hamstring muscles. The criterion score was the maximum angle (degree) read from the inclinometer at the point of maximum knee extension. The ankle of the tested leg was restrained in plantar flexion to avoid adverse neutral tension.[30] Two trials were conducted for each leg and the average of the two trials was used for subsequent analyses.

## Statistical Analysis

Intratester reliability of thoracic and lumbar curvatures, pelvic tilt, and hamstring muscle extensibility were calculated in two previous pilot studies. The first one, in twenty subjects who did not participate in the final sample were measured three times by the same tester in standing position on the floor, sitting on a stool, and lying down in a single session. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) and mean differences (SEM) among the three measures in each posture were calculated. An ICC above or equal to .98 (95% CI: .98–.99) was obtained for thoracic kyphosis, lumbar lordosis and pelvic tilt in all postures evaluated. The intraexaminer SEM ranged from .50° for the pelvic tilt in standing to .15° for the thoracic spine in sitting posture. In the second one, intratester reliability of hamstring muscle extensibility by the Passive Knee Angle test was calculated in twenty subjects who did not participate in the final sample. Both legs were measured three times by the same tester. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) were calculated. An ICC above or equal to .91 (95% CI: .91–.99) was obtained for the left and right legs. The intraexaminer SEM ranged from 1.20° to .16° for both legs.

Means and standard deviations (SD) were calculated for all variables. The hypothesis of normality was analyzed using the Kolmogorov-Smirnov test. Because the sample showed normality, parametric tests were performed. A one-way ANOVA was used to compare spinal curvatures and pelvic tilt among all postures analyzed. The significance of the repeated multivariate measurements was confirmed by Wilks's lambda, Pillai's trace, Hotelling trace, and Roy's tests, all of which obtained similar results. If a significant $P$-value was obtained for the main effect of the ANOVA, a post hoc comparison was conducted using Bonferroni correction for multiple comparisons, which adjusted the significance criterion to a value of 0.01 (0.05/5). Pearson's product moment correlation coefficients ($r$) were used to determine the relationship between the hamstring muscle extensibility (measure with popliteal angle) with respect to sagittal spinal curvatures (thoracic and lumbar) and pelvic tilt. The $R$-square ($R^2$) and regression line (least-squares) were calculated to each pair of variables. The data were analyzed using the SPSS v.18.0. The level of significance was set at $P \leq .05$.

# Results

The ANOVA analysis reported that the thoracic spine showed greater degrees in standing posture than when cyclists were on their bicycles with the lowest handlebar-hands position ($P < .01$). Lumbar spine changed from lordosis (anterior convexity) in standing posture to kyphosis (posterior convexity) in other postures analyzed. Pelvic tilt presented a posterior inclination in sitting and sit-and-reach test (Table 2).

The Pearson correlation coefficients showed a low and inexistent relationships between hamstring muscle extensibility and spinal parameters (thoracic and lumbar curvature, and pelvic tilt) in standing, slumped sitting, maximal trunk flexion with knee flexed, and on the bicycle (Figures 1, 2, 3 and 5). In sit-and-reach test, statistically significant relationships were found between hamstring muscle extensibility and spinal parameters (Figure 4). However, thoracic spine showed a low and

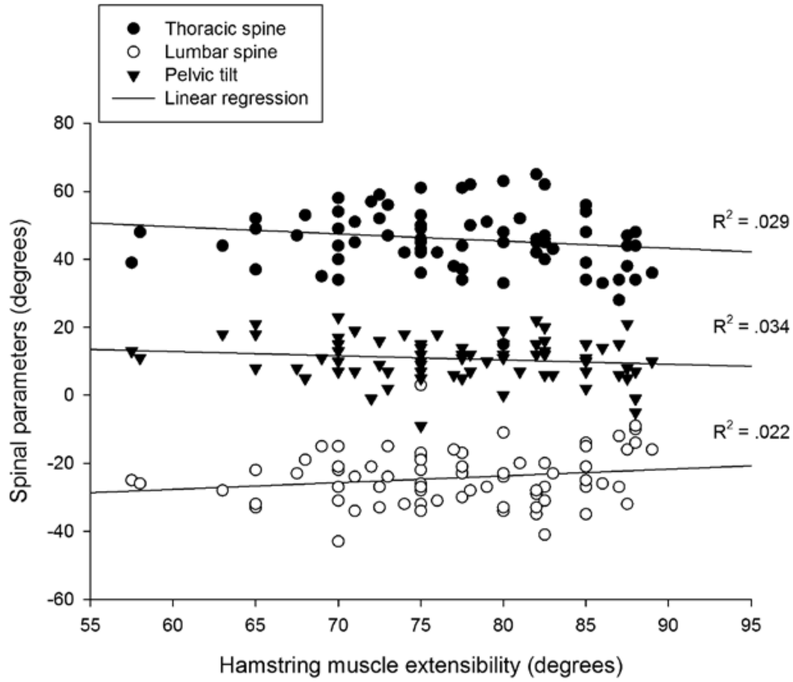


**Figure 1** — Correlation and linear regression curves between spinal parameters (thoracic spine, lumbar spine and pelvic tilt) and hamstring muscle extensibility (measure with passive knee extension test) in standing posture.

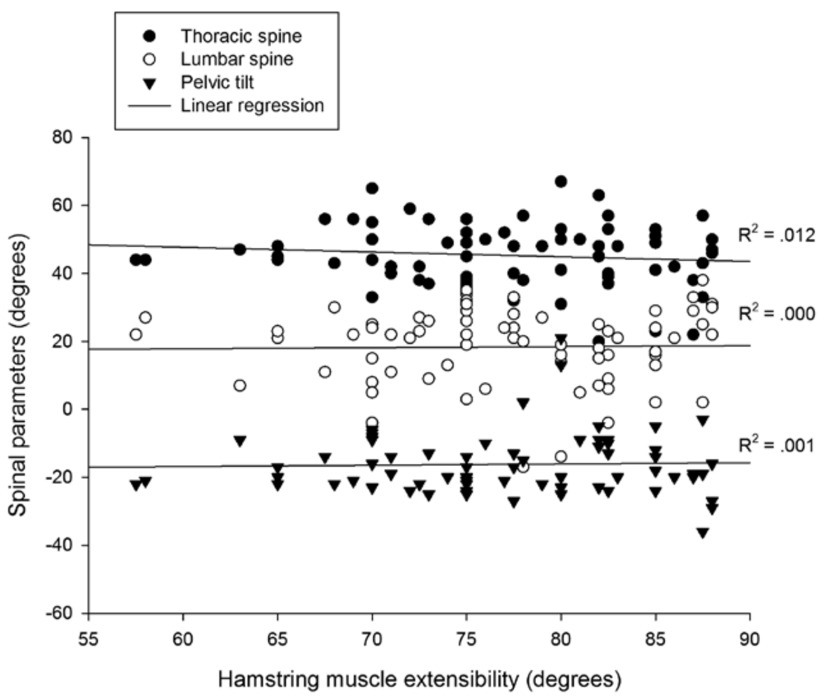


**Figure 2** — Correlation and linear regression curves between spinal parameters (thoracic spine, lumbar spine and pelvic tilt) and hamstring muscle extensibility (measure with passive knee extension test) in slumped sitting.

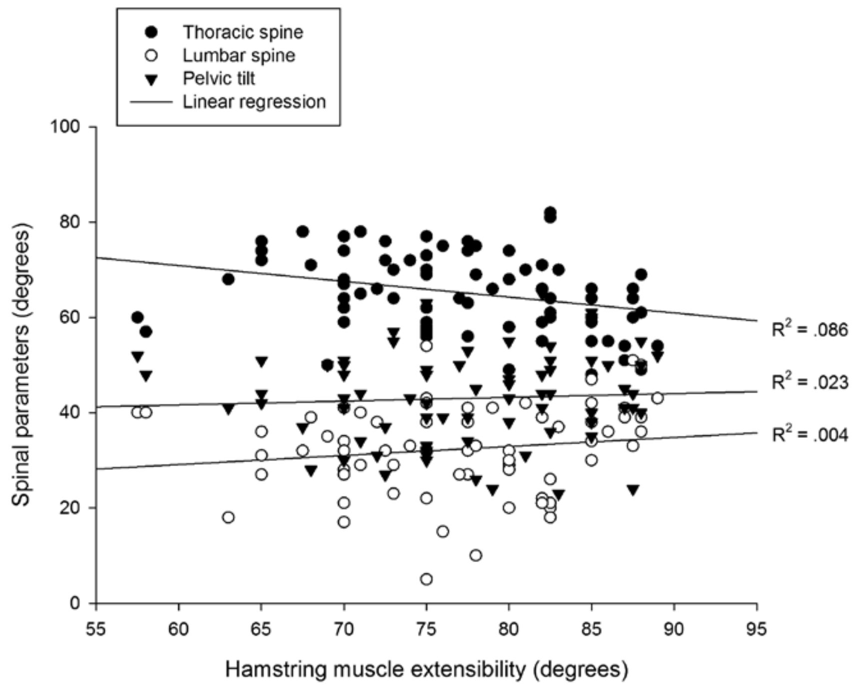


**Figure 3** — Correlation and linear regression curves between spinal parameters (thoracic spine, lumbar spine and pelvic tilt) and hamstring muscle extensibility (measure with passive knee extension test) in maximal trunk flexion with knees flexed.

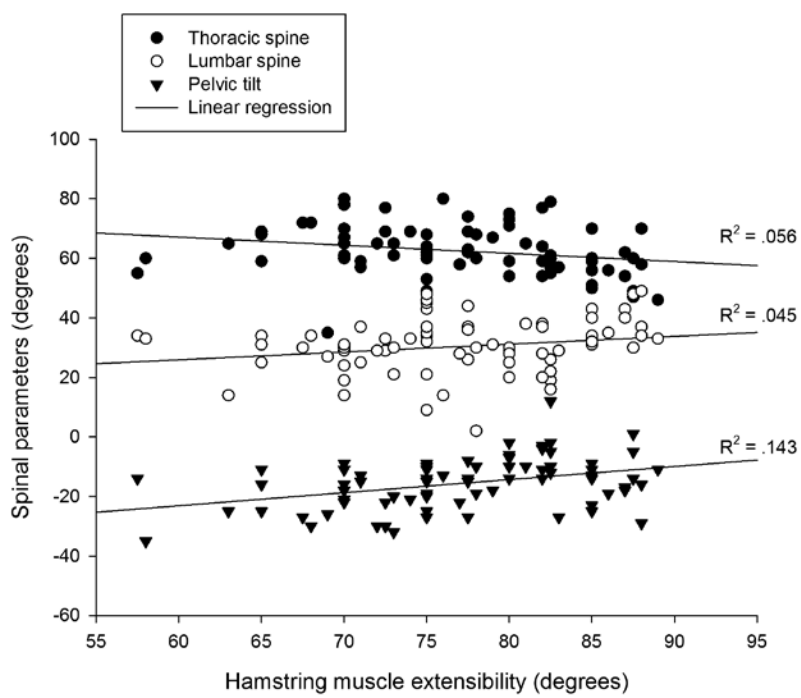


**Figure 4** — Correlation and linear regression curves between spinal parameters (thoracic spine, lumbar spine and pelvic tilt) and hamstring muscle extensibility (measure with passive knee extension test) in maximal trunk flexion with knees extended (*sit-and-reach test*).

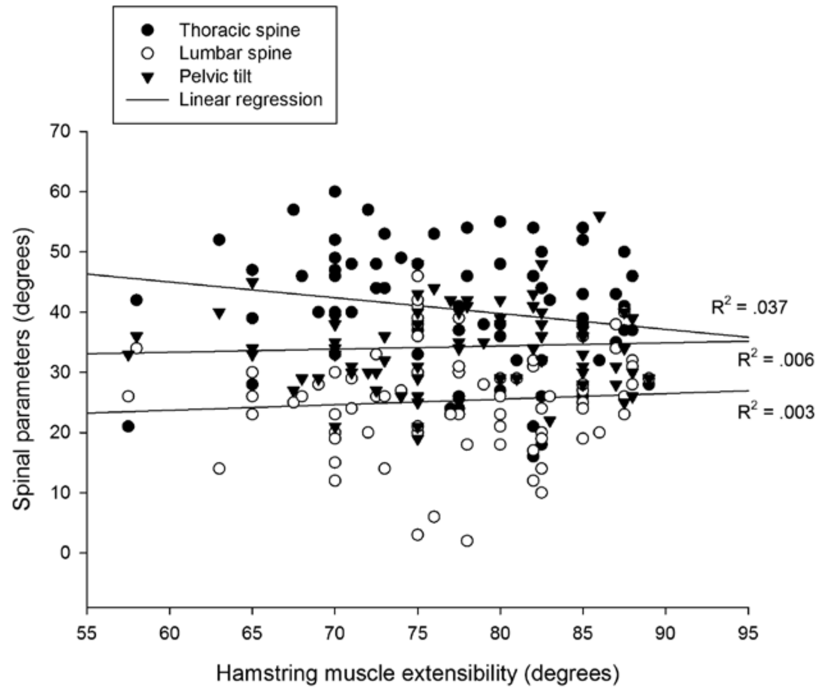


**Figure 5** — Correlation and linear regression curves between spinal parameters (thoracic spine, lumbar spine and pelvic tilt) and hamstring muscle extensibility (measure with passive knee extension test) on the bicycle with lower handlebar-hands position.

negative relationship ($r$ = –.23; $P$ = .001), and lumbar spine, although positive, was lower ($r$ = .21; $P$ = .05). Pelvic tilt shows a low relationship ($r$ = .37; $P$ = .001) with hamstring muscle extensibility.

## Discussion

The main purpose of this study was to determine the relationships between hamstring muscle extensibility (measured as the passive knee extension test) and the sagittal spinal curvatures and pelvic tilt in several postures, and while on their own bicycles.

Clinical observations suggest that hamstring muscle extensibility may be associated to specific pelvic and trunk postures.[14] Furthermore, several studies have reported that sports practice where there is a prevalence of postures with trunk in flexion produces structural modifications on spinal curvatures,[9–13] although these studies did not take into account the influence of the hamstring muscle extensibility on the spinal curvatures and pelvic tilt. In this sense, cycling is a sport where cyclists spend a lot of hours with the lumbar spine flexed to keep their hands on the handlebar-hands.[10–12]

The main finding of the current study was that it did not find statistical and significant relationships between hamstring muscle extensibility and spinal curvatures in three (standing, slumped sitting, and on their bicycles) of the five postures analyzed. Toppenberg and Bullock[18] found that hamstring muscle extensibility was significantly and negatively correlated to the lumbar lordosis in a standing posture, although the score of correlation was low ($r$ = –.21; $P$ < .05). The differences in these results with respect to our finding could be because the samples analyzed by these authors were sedentary adolescents who could have shorter hamstring muscle extensibility than cyclists analyzed in the current study. Gajdosik et al.[14,17] showed that thoracic and lumbar curvatures are not influenced by hamstring muscle extensibility. A possible explanation for this might be that the hamstring muscles are slightly stretched with little passive tension in a standing posture.[31]

McCarthy and Betz[20] reported a significant correlation between tight hamstrings and decreasing lumbar lordosis, especially when sitting in children with cerebral palsy. They observed that children with tight hamstrings showed a hypolordotic or even kyphotic lumbar spine in sitting, but they did not explain a possible cause for their finding. However, in the current study there were no relationships between spinal parameters and hamstring muscle extensibility, but a change from lumbar lordosis in standing posture to lumbar kyphosis (lumbar inversion) in slumped sitting was found. Our results are in concordance with López-Miñarro & Alacid[23] in young athletes and Muyor et al[11] in cyclists. The loss of lumbar lordosis in sitting may be due to a wrong postural schema or the lumbar adaptation to maintain in flexion postures in their specific sport techniques. Moreover, we did not find strong relationships between hamstring muscle extensibility and spinal parameter in maximal sitting with knees flexed. This also corresponds to earlier observations in the current study where standing posture, which showed that when the origin (ischial tuberosity of the pelvis) and insertion (tibia and fibula) are close to each other, there is a reduction in the tension on hamstring muscles and limits its influence on spinal curvatures and pelvic tilt.

Another important finding was that there were no relationships between hamstring muscle extensibility and spinal parameters on their own bicycle. Recently, Muyor et al[26] analyzed the influence of hamstring muscle extensibility on spinal curvatures and pelvic tilt on the bicycle in highly trained cyclists. Although these authors used the passive straight leg raise test to identify muscle hamstring extensibility and divided the sample into two categories with respect to the hamstring muscle extensibility index, they did not find any correlation between hamstring muscle extensibility and the specific posture on the bicycle. This could be explained because the knees were not completely extended during pedaling despite resting their hands on the lowest handlebar-hands, where the trunk is more flexed.

It is necessary to highlight that the thoracic spine was straighter on the bicycle posture than while standing on the floor, without the influence of the hamstring in either posture analyzed. These results are in concordance with previous studies[10–12,26] which were designed to find if cyclists' higher hyperkyphosis in standing posture was due to the specific posture on the bicycle. With the current study we can report that hamstring muscle extensibility does not influence either posture (standing on the floor and on the bicycle).

Only in maximal trunk flexion posture with knees flexed and extended (sit-and-reach test) significant correlations between hamstring muscle extensibility and spinal curvatures and pelvic tilt were found. Cyclists who have greater hamstring muscle extensibility showed lower thoracic flexion degrees, and greater lumbar spine flexion and anterior pelvic tilt. These results are consistent with previous studies which showed that long hamstring muscles were associated to increased flexion range of motion (ROM) of lumbar spine and decreased flexion ROM of the thoracic spine.[30,33] Sahrmann[34] calls this situation "relative flexibility." It states that increased stiffness of one muscle group can cause compensatory movement at an adjoining joint that is controlled by muscles or joints with less stiffness.

In young athletes, López-Miñarro & Alacid[23] found that hamstring muscle extensibility influences the thoracic and pelvic postures when the maximal trunk flexion with knees extended was performed. In line with our study, the kayakers who had lower hamstring extensibility presented a high thoracic flexion and posterior pelvic tilt. Bellew et al[22] found that hamstring flexibility strongly correlated between pelvic rotation and forward bending range. In cyclists, McEvoy et al[25] found an increased anterior pelvic tilt in elite cyclists in comparison with sedentary subjects while long sitting was adopted. These authors justified these results as adaptation to the posture adopted during training in cycling. However, with the findings in our study, we think that those results could be because the cyclists had greater hamstring muscle extensibility than sedentary subjects, although it also had the influence of training.

In the current study we observed higher and significant correlation between pelvic tilt and hamstring muscle extensibility than with the thoracic spine in maximal trunk flexion posture with knees extended. This may be explained by the origin and anatomical insertion of hamstring muscles where they are in maximal tension. In contrast with our results, Norris and Matthews[21] did not find any association between hamstring muscle extensibility and total angle pelvic tilt in people with extensibility of the hamstrings within normal limits. These finding may be because the subjects analyzed did not reach maximal trunk flexion.

During maximal trunk flexion with knees extended (sit-and-reach test) we did not find a strong relationship between hamstring muscle extensibility and lumbar spine. These results confirm previous studies. Gajdosik et al[17] reported no association between hamstring extensibility and lumbar flexion. Recently, López-Miñarro et al[24] did not find significant differences in lumbar curvature when sitting on their kayaks in two groups of highly trained young kayakers who were divided in accordance to their hamstring extensibility. However, the current study reports that the lumbar spine is inverted (posterior convexity) during sit-and-reach test such as in sitting postures. Moreover, the sit-and-reach posture is commonly performed by cyclists before and after their training as a stretching exercise for the lower back and the hamstring muscles. Increased spinal loads,[2] and intradiscal pressures[4] have been related to static and cyclic flexion postures. Although in the current study we did not find relationships between hamstring muscle extensibility and spinal curvatures and pelvic tilt in cyclists with regards to standing, slumped sitting, and on their own bicycles postures, it is recommended to carry out specific stretching and postural exercises, before and after the training, with the spine maintaining its physiological curvatures, with special attention on flexion postures with knees extended.

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