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Straight Leg Raise Test: Influence of Lumbosant© and Assistant Examiner in Hip, Pelvis Tilt and Lumbar Lordosis

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Abstract: The passive straight leg raise (PSLR) test is widely used to assess hamstring extensibility. However, to accurately measure hamstring extensibility throughout PSLR, appropriate stabilization of the pelvis must be provided in order to minimize the possible influence of any compensatory movement in the scores reached. The main purpose of this study was to demonstrate the degree of influence of the Lumbosant© and an assistant examiner in hamstring extensibility in healthy young adults. A secondary objective was to verify the variability of the posterior pelvic tilt movement. Hamstring muscle extensibility was measured using the traditional (only an examiner) and new (using a low-back protection support Lumbosant© and two trained [principal and assistant] examiners) PSLR procedures. Correlation coefficients were expressed using r values, accompanying descriptors and 90% confidence intervals. Variance explained was expressed via the R^2 statistic. To examine possible differences, the Mann-Whitney U-test was conducted. Additionally, Cohen's d was calculated for all results, and the magnitudes of the effect were interpreted and statistical significance set at $p < 0.05$. A stepwise multiple regression analysis was performed to examine the relationship between scores and values. The final score that was determined with the new PSLR is significantly lower (13° approximately) than the one obtained through the traditional procedure (75.3 ± 14.4° vs. 89.2 ± 20.8°; d = −0.777 [moderate]). The data presented in this study suggest that the PSLR may overestimate hamstring extensibility unless lumbopelvic movement is controlled. Therefore, we recommend the use of Lumbosant© and an auxiliary examiner to obtain more accurate hamstring extensibility scores.

Keywords: flexibility; angular test; validity; angle assessment

1. Introduction

The assessment of hamstring extensibility is a common practice in both clinical and sport settings. Poor hamstring extensibility has been associated with alterations in gait patterns [1], changes in lumbopelvic rhythm [2–4], spine disorders (e.g., thoracic hyperkyphosis [5–8] and lumbar hyperkyphosis [5–7,9–11]) and low back pain [12–14]. Furthermore, in team sport athletes, an inadequate level of hamstring extensibility has been suggested as a primary risk factor for muscle strains [15–17], plantar fasciitis [18], knee injuries [19,20] and low-back disorders [21–23], such as spondylolysis [24,25] and disc herniation [26,27].

Radiography has been considered as the criterion measurement (gold standard) to assess hamstring extensibility due to its high level of accuracy and reliability [28,29]. However, the use of radiography is very restricted to research settings and not used in either clinical nor sport environments or for pre-participation screening because of their potential health-related consequences (attributed to exposing individuals to radiation), high cost, lack of portability, time constraints and the need for sophisticated instruments and qualified technicians [30]. As alternatives to the radiography, several field-based testing maneuvers have been described to assess hamstring extensibility, such as the sit-and-reach [5,7,31], passive straight leg raise (PSLR) [32–34], knee extension angle test [3,35,36] and horizontal hip joint angle in trunk flexion tests [5,7,13]. It is widely accepted that the selection of a test should be based first on the criteria of high validity and reliability, and then, to value simplicity and universality of the procedure [37].

A critical review of the most popular field-based tests conducted by Ayala et al. [31] concluded that, according to the just mentioned selection criteria, the PSLR test may be the best alternative to the gold standard (radiography) when assessing hamstring extensibility. However, and in line to what was previously stated by some authors [27–33,36–38], this review also suggested that the accurate assessment of hamstring extensibility through the PSLR test requires an adequate stabilization of the pelvic to avoid any compensatory movement that may bias the final score achieved. In 1982, Bohannon [38] attempted to alleviate this problem by using three different systems to fix the pelvis during the execution of the PSLR. Specifically, the first method was a stabilizing strap that was placed across the left thigh midway between the anterior superior iliac spine (ASIS) and proximal patella and another strap across the middle of the anterior pelvis. The strap across the pelvic was positioned slightly diagonally so that the line between the ASIS and posterior superior iliac spine (PSIS) was visible. The second method of stabilization was two straps placed across the left thigh, one placed proximally and the other distally., The third method of stabilization required the subject to flex the left knee over the end of the table. The left lower leg was then stabilized against the table legs with one strap; the other strap was placed midway between the ASIS and patella. None of these three different methods seem to have been widely used either in clinical or in sport settings. In addition, their efficacy to stabilize the pelvis was reported as sub optimal [38]. In another study, Bohannon et al. [38] also recommended the use of a towel to maintain the lumbar curvature in a neutral position. However, this method does not maintain the lumbar curvature always in a neutral position as the body mass of the patient or athlete may have an impact on the degree of the towel deformation.

Recently, Cejudo et al. [30] have suggested, as alternatives to the straps and towel, the use of an assistant tester to provide suitable stabilization of the pelvis during the PSLR assessment maneuver and a rigid (non-flexible) low back protection support (Lumbosant©) to standardize the lordotic curve (20°). However, before promoting the new version of the PSLR test suggested by Cejudo et al. [30], the efficacy of the measures adopted to avoid or minimize any compensatory movements that may bias the final score should be analyzed. Therefore, the main objective of the present study was to evaluate the influence of the Lumbosant© and an assistant examiner on scores attained in the assessment of hamstring extensibility through PSLR test using radiography in healthy young adults. A secondary objective was to verify the variability of the retroversion movement of posterior pelvis tilt and a simultaneous decrease in lumbar lordosis after the application of the passive straight leg raise test in healthy young adults. The initial hypothesis was that when the traditional PSLR is performed, a posterior pelvic tilt movement would occur and lumbar lordosis would decrease, which implies that the traditional PSLR overestimates the extensibility of this musculature. Conversely, using a low-back protection support and a trained auxiliary test administrator, the score will be more sensitive as the compensatory movements decrease.

2. Materials and Methods

A descriptive-correlational design was used to describe and compare the hamstring extensibility measure achieved through both PSLR tests (traditional vs. new). To analyze the influence of hip flexion on the score achieved during the PSLR, a stepwise multiple regression analysis was performed. Analyses were performed for the entire sample, and separately by sex.

2.1. Participants

Twenty-three healthy adults aged 23.6 ±1.6 (range, 23–28) years old of both sex (10 males, 13 females) voluntarily participated in the present study. Mean stature was 1.69 ± 0.07 m, mean body mass was 68.1 ± 13.8 kg and mean body mass index was 25.7 ± 3.7 kg/m^2 (Table 1). The participants were recruited through advertisements at a Faculty of Medicine. All the participants were medical students, who did not perform any systematic practice of physical exercise or sport. All participants were healthy and had no known metabolic, neuromuscular or musculoskeletal disorders, no history of low back pain and no pain in any part of the body at the time of testing [39].

Table 1. Results of demographic, hamstring extensibility, pelvic tilt and lumbar curvature data in 23 students according to gender.

		Male (*n* = 10)	**Female (*n* = 13)**	**Total (*n* = 23)**
	Age (years)	23.80 ± 1.55	23.38 ± 1.71	23.57 ± 1.62
	Body mass (kg) *	77.00 ± 11.28	61.22 ± 11.79	68.08 ± 13.85
	Height (m) *	1.73 ± 0.06	1.66 ± 0.07	1.69 ± 0.07
	BMI (kg/m^2) *	25.66 ± 3.72	20.19 ± 6.96	22.57 ± 6.31
I	T_PSLR (degrees) *	79.4 ± 11.2	96.8 ± 23.6	89.2 ± 20.8
I	N_PSLR (degrees) *	68.0 ± 11.0	80.9 ± 14.5	75.3 ± 14.4
Rx	PT _ neutral position (degrees)	44.1 ± 11.6	40.7 ± 8.0	42.2 ± 9.6
Rx	PT _ T_PSLR (degrees)	17.7 ± 11.7	19.5 ± 7.9	18.7 ± 9.5
Rx	PT _ N_PSLR (degrees)	27.5 ± 11.5	27.5 ± 5.9	27.5 ± 8.5
Rx	LL _ neutral position (degrees)	57.6 ± 15.6	58.5 ± 12.9	58.1 ± 13.8
Rx	LL_ T_PSLR (degrees)	24.7 ± 13.3	28.5 ± 12.1	26.8 ± 12.5
Rx	LL_ N_PSLR (degrees)	38.4 ± 16.8	39.0 ± 8.7	38.7 ± 12.5

Values are expressed as mean ± standard deviation (in degrees); BMI: body mass index; I: hip flexion degrees evaluated with the inclinometer in the PSLR test; T_PSLR: Traditional passive straight leg raise test; N_PSLR: new passive straight leg raise test; Rx: angle measured on the radiography; LL: lumbar lordosis; PT: pelvic tilt; * significance statistic according to body mass, height, BMI, T_PSLR (I) and N_PSLR (I) ($p \leq 0.027$).

The exclusion criterion was a history of orthopedic problems in the knee, thigh, hip or lower back in the last 3 months due to the fact that residual symptoms could have an impact on the habitual students' movement competency as well as presenting delayed onset muscle soreness at the time of being evaluated or inability to achieve relaxation during testing [36].

Before any participation, experimental procedures and potential risks were fully explained to medical students in verbal and written form, and written informed consent was obtained. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics and Scientific Committee of the University of Murcia (Spain) (ID: 1702/2017; ID: 2063/2018).

2.2. Testing Procedure

A week before the testing session commenced, the participants were familiarized with the tests to reduce the influence of learning on the measurement [33]. All tests were carried out by the same two sport scientists (one conducted the tests and the other ensured proper testing position of the participants throughout the assessment maneuver) under stable environmental conditions. The sport scientists were blinded to the purpose of the study.

The previous analysis did not show asymmetry in the hamstring extensibility. Hamstring extensibility was measured clinically by the PSLR following the traditional [40,41] and new [30–42] procedure. In the traditional PSLR procedure (T_PSLR), only one examiner made the measurement, and in the new PSLR procedure (N_PSLR), two examiners (principal and assistant) and a low-back protection rigid support called Lumbosant© (Imucot Traumatología SL, Murcia, Spain) were used (Figure 1). In order to eliminate the order effect, the order of the PSLR tests (T_PSLR, N_PSLR) was counterbalanced.

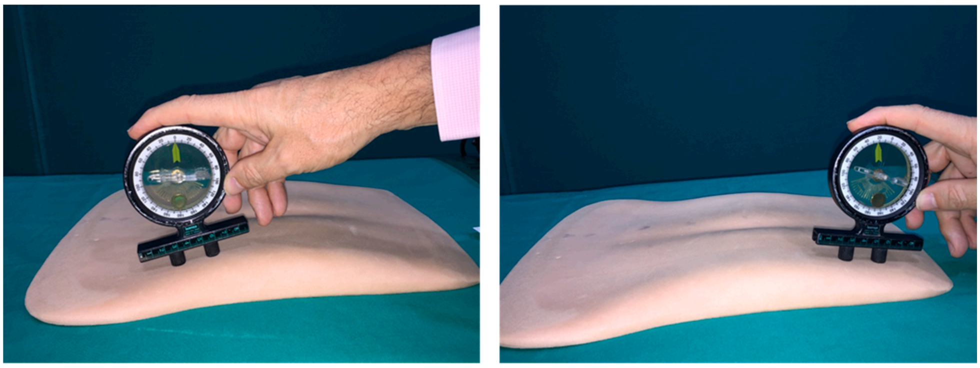

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Figure 1. Lumbosant© a rigid support with a normal lordotic curvature (lordosis of 20 degrees). Assessment of lumbosant's curve (**a**) inclinometer calibrated to 0° and (**b**) grade of lumbar lordosis.

To obtain radiographic projections, after placing the radiological protections for the examiner, three lateral X-rays of the lumbar spine and pelvis were taken, in the initial position (0° or neutral position) and the end of the PSLR test, traditional and new, in a randomized order. In the radiographic measurement, the left limb was measured to prevent interference in radiographic projection, so that the assistant examiner did not obstruct the vision of the collimator of the X-ray apparatus (Figure 2).

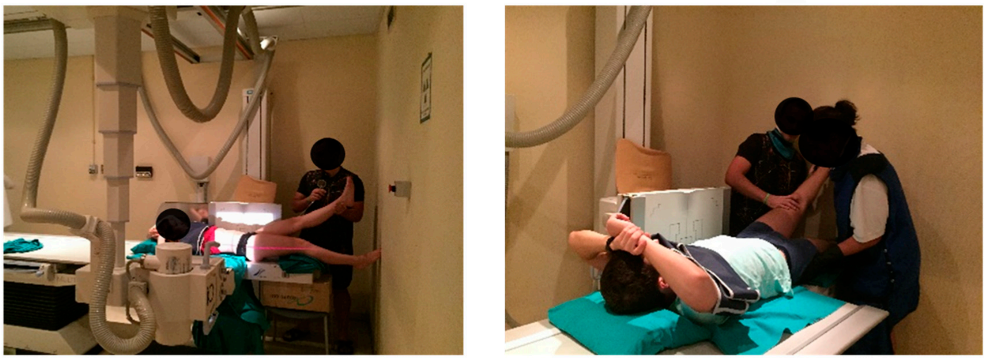

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Figure 2. Positioning and traditional (**a**) and new passive straight leg raise (PSLR) (**b**) procedure for a lateral radiograph of the lumbar and sacral spine.

Participants were allowed to rest for 30 seconds between the tests. This time was selected because: (a) it reflects the typical period of time existing for clinical assessment in daily clinical practice; (b) it is consistent with similar previous studies [30].

Recommendations reported in the literature were used in an attempt to estimate range of motion [43]. Before the testing procedure, its purpose was explained to the participants, describing exactly what would be taking place and how the measurement must be performed. Then, all participants were positioned supine for the measurement. Movements in supine allow for support of the trunk permitting greater relaxation of the participant [44]. Finally, the main explorer moved the students' distal joint segment passively through the range of motion (ROM). Participants were instructed to perform two trials, one practice trial and one maximal trial. The reason to assess only one maximal trial was to minimize the radiation exposure in the X-ray assessment (according to the consensus paper by SOSORT, "The universal desire is to minimize the amount of X-ray exposure").

2.2.1. Testing Measurement

Students were instructed not to participate in any training or physical activity 24 h before their assessment [45]. Furthermore, participants did not perform any strenuous physical exercise during the 36–48 h prior to each testing session. All the measurements were performed on the same day, starting with anthropometric measurements. Body height was measured with the Seca 213 mobile stadiometer (SECA 213, Hamburg, Germany), with an accuracy of 0.1 cm. Body mass was measured using the electronic scale OMRON BF 500 (Omron Healthcare, Inc USA), with an accuracy of 0.1 kg. The measurements were performed in standard conditions. All measurements were carried out during the same testing session, administered at the same time every day and under the same environmental conditions (room temperature at 24 °C). Testing took place in the radiology room. No warm-up or stretching exercises were performed by the participants before the test measurements.

Each participant was examined in sportswear and without shoes. For the measurement, an ISOMED Unilevel inclinometer (Portland, Oregon) was used with an extendable telescopic arm [30–46]. The inclinometer was calibrated to 0° with the horizontal axis. The angle between the longitudinal axis of the mobilized segment was recorded (following its bisector) with the horizontal [30–42].

The PSLR test was performed on all subjects in both traditional and new procedure. The participant was placed in the supine position with their legs straight and the ankle of the tested leg in a relaxed position to avoid the possible influence of gastrocnemius tightness on the scores [47]. The participant's head was supported by a pillow. The test administrator placed the inclinometer (ISOMED, Portland, Oregon) on the distal leg at the level of the lateral malleolus and the free hand was placed over the knee to keep it straight. This inclinometer was consistently placed level with the table top before each testing session. The participant's leg was lifted passively by the principal tester into hip flexion.

For the new PSLR procedure, a Lumbosant© was used to maintain the normal lordotic curve [30–34]. Furthermore, a trained assistant examiner kept the contralateral leg straight to avoid external rotation, fixed the pelvis to prevent posterior pelvic tilt, sinking of the contralateral hemipelvis to the movement, and to avoid counter-clockwise rotation of the pelvis (initial position) [30–34].

The endpoint for PSLR was determined by one or more of the following criteria: (1) the main examiner is unable to continue the stretching maneuver due to elevated resistance of the muscle groups tested; (2) one or both examiners palpate or appreciate some accompanying movements that increase the ROM onset of pelvic rotation; and/or (3) the participant feeling a strong but tolerable stretch, slightly before the occurrence of pain [30–48]. Recommendations reported in the literature were used in an attempt to estimate range of motion and determining end-feel during the procedure [49].

In order to analyze the reliability of the measures, both tests were conducted twice with the same 15 participants (randomly selected), with an interval rest of 5 minutes in a single session. Intraclass correlation coefficient (ICCs; intraobserver reliability) with 95% confidence intervals (CI) were calculated. The ICC values for the traditional PSLR test was 0.92 (95% CI 0.81–0.97) and for the new PSLR test 0.97 (95% CI 0.93–0.99). All the tests were conducted by the same research examiner as principal with or without help (assistant examiner). Furthermore, a study from our laboratory have reported moderate to high absolute reliability (three different occasions, with a two-week interval between testing sessions) for the PSLR procedures employed (MDC_{95}: 6.1°; ICC: 0.91) [30].

2.2.2. Radiographs. Image Acquisition

This study involved students undergoing lateral lumbar and sacral spine radiograph examinations in the imaging department at the Clinical University Hospital Virgen de la Arrixaca, Murcia, Spain.

Standard lateral lumbar and sacral spine radiograph were obtained with the participant in a supine position. Each participant was positioned on the radiographic table with a pillow for the head and with his or her legs straight and the ankle of the tested leg in a relaxed position.

The image was taken with a tube-to-film distance of 100 cm (1 m) centering the Central Ray to the iliac crest level (L4-L5) to capture both the lumbar spine and sacrum. Central Ray was taken using a 14 × 17 inch (35 × 43 cm) cassette and 75–90 kVp range for the lumbosacral spine depending on the participant´s size (e.g., 165 cm and 55 kg. = 75 kv (kilovoltage) and 55 mAs (milliampere-second product), with a tube-to-film distance of 1 meter; 175 cm and 70 kg = 85 kv y 65 mAs, with a tube-to-film distance of 1 m.).

A conventional SIEMENS radiography system with a VERTIX PRO Bucky wall stand (Polydoros RF Rad 80 X-ray Generators) was used (Siemens Healthcare, Erlangen, Germany). The modular design of the Rad 80 family incorporates high versatility and excellent adaptation to all requirements of radiography applications. The generators for standard X-ray tube assemblies are available with a nominal power from 55 kW to 80 kW.

2.2.3. Radiographic Measurement

On the lateral projection of the lumbar and sacral spine, the vertebral bodies are seen in profile and the superior and inferior end plates are well demonstrated. The radiographic was quantified using the method described by Cobb [50]. Several measurements were obtained from each radiograph (Figure 3), all of them expressed in degrees. A positive value is posterior, a negative value anterior. The following parameters were measured:

- The pelvic tilt (angle S1): the angle between the vertical and the line connecting the midpoint of the upper plate of S1.
- Lumbar lordosis: the angle between the superior sacral plate and the more backward tilted vertebral plate (using the method described by Cobb).
- Vertebral wedge angle: The wedge angle is defined as the angle formed between the two lines drawn parallel to the superior and inferior endplates of the vertebra.

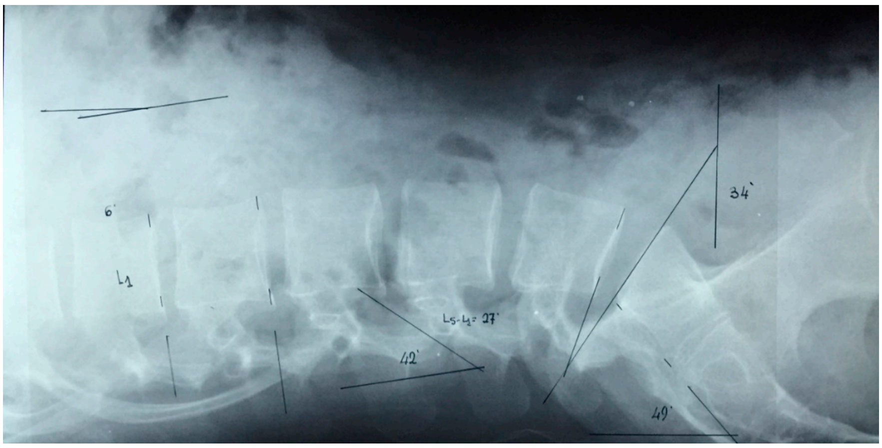

Figure 3. Lateral radiograph of the lumbar and sacral spine in the supine position, which shows the measurement of lumbar lordosis (42°) [angle of lumbar lordosis] and the inclination of the upper plate of S1 with the vertical (34°) [angle of pelvic tilt]. There is a vertebral wedge of 6° in L1.

All measurements were made by the same observer (orthopedic surgery expert with more than 35 years' experience in the medical field). Intraclass correlation coefficients (ICCs; intraobserver reliability) of measurements of the radiographic (15 radiographs randomly selected) were performed for one observer in two sessions at least 2 weeks apart. The ICC ranged from 0.92 to 0.99. The ICC values for the lumbar lordosis was 0.98 (95% CI 0.96–0.99) and for the pelvic tilt 0.97 (95% CI 0.92–0.99).

Only radiographs adjudged to be normal by the observer were selected for study. The criteria for normality were (1) presence of at least five lumbar vertebrae and three sacral vertebrae; (2) no radiographic evidence of disease or congenital abnormality in the lumbosacral spine. The exclusion criteria included poor quality radiographs and radiographs showing any evidence of disease or congenital abnormality.

2.3. Sample Size Calculation

To identify the minimum acceptable sample size for the study, a power analysis was conducted using G*Power version 3.1.9.4, based on a power of 0.80 or 80%, a moderate effect size, and an alpha of 0.05 [51]. Based on the calculation, a minimum sample size of 13 was needed for the study. However, we enrolled 23 participants to ensure that we had sufficient observations.

2.4. Statistical analysis

Prior to the statistical analysis, the distribution of raw data sets was checked using the Shapiro-Wilk test and demonstrated that all data were not normally distributed ($p < 0.05$). For all analyses, significance was accepted at $p < 0.05$.

The independent sample Wilcoxon test was carried out to assess differences between the PSLR values of corporal sides. To examine possible differences in demographic, hamstring extensibility, angle of pelvic tilt and angle of lumbar lordosis measures between the male and female groups for each movement, the Mann-Whitney U-test was conducted. Additionally, Cohen's d was calculated for all results, and the magnitudes of the effect were interpreted according to the criteria of Hopkins et al. [52], in which the effect sizes less than 0.2, from 0.2 to 0.59, from 0.6 to 1.19, from 1.20 to 2.00, from 2.00 to 3.99 and greater than 4.00 were regarded as trivial, small, moderate, large, very large and extremely large, respectively. The authors arbitrarily chose moderate as the minimal relevant effect level with practical application in the results.

A Spearman correlation (r) analysis of the correlation of hamstring extensibility, angle of pelvic tilt and angle of lumbar lordosis (in degrees) in both types of procedure (traditional procedure vs. new procedure) was calculated. In addition, a nonlinear regression was used to determine if the hamstring extensibility predicts the degree of angle of pelvic tilt and angle of lordosis lumbar.

Ninety percent confidence intervals (CI) were used to describe the uncertainty in the data and magnitudes of relationships were described using the following intervals: Trivial 0–0.2, Small 0.1–0.3, Moderate 0.3–0.5, Large 0.5–0.7, Very Large 0.7–0.9 and Nearly Perfect >0.9 (Hopkin, 2009). Variance explained was expressed via the R^2 statistic. A nonlinear regression was used to determine the predictive ability of both PSLR, and angle of lumbar lordosis and angle of pelvic tilt, with relationships described using the formula $y = a + bx$; where y (traditional or new procedure) is the dependent variable score, A is the intercept on the y axis, B is the slope of the regression line and x is "new procedure or angle of lumbar lordosis."

All statistical analyses were performed with the SPSS 24.0 evaluation software (SPSS Inc, Chicago, IL, USA).

3. Results

Among the variables that were assessed in the study, the only significant difference detected between the groups (men vs. women) was in body mass, height and body mass index ($p \leq 0.018$), as well as the clinical measures of the traditional PSLR test (T_PSLR) and new PSLR test (N_PSLR). Means and SDs for each variable of the male and female students are presented in Table 1. The descriptive analysis found no asymmetry in hamstring extensibility in the clinical measure.

The results of the Table 1 show that the score reached with the new version of the PSLR is consistently lower when it is compared with the score reached with the traditional version. Thus, in the clinical assessment of hamstrings extensibility (measurement with inclinometer in the radiology room), when the Lumbosant© and the assistant examiner is used, the score is 13.9° lower in comparison with the traditional procedure (75.3 ± 14.4° vs. 89.2 ± 20.8°; d = −0.777 [moderate]) (Figure 4).

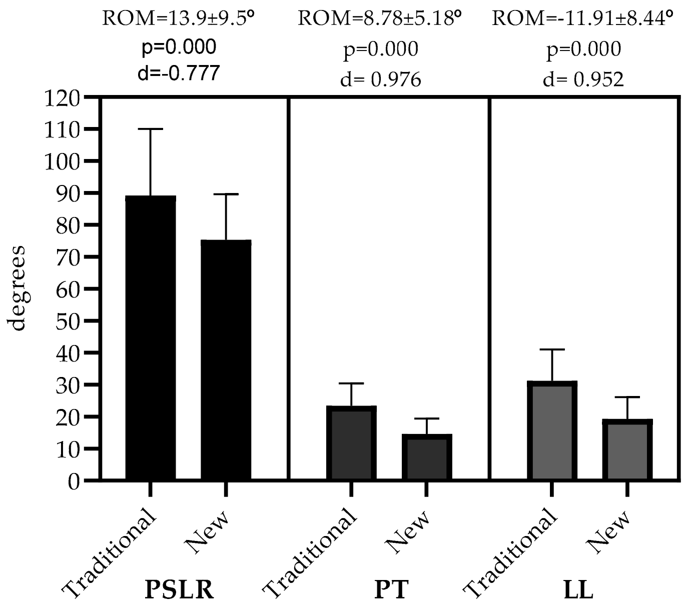

Figure 4. Results of hamstring extensibility, pelvis tilt and lumbar lordosis according to type of procedure (traditional procedure vs. new procedure).

In relation to the measurements in the lateral radiograph of the lumbar and sacral spine when we analyze the differences in each angle between the radiography in the starting position and the radiography at the end of the test, the reduction of the tilt of the pelvis is evident in both procedures (Table 2). However, the difference between the angle S1 in the neutral position and in the final position is lower with the N_PSLR test. Thus, the difference between both angles is 23.5° and 14.7° in the T_PSLR and N_PSLR test respectively. Therefore, there is a significant difference of 8.78° between both procedures (14.7° ± 4.77° vs. 23.48° ± 7.0°; d = −0.976 [moderate]) (Table 2).

In relation to the lumbar curvature, when we analyze the differences between the radiography in the starting position and the radiography at the end of the test, the reduction of the lumbar lordosis is evident, in both procedures. However, the difference between the angle of the lumbar lordosis in the neutral position and in the final position is lower with the N_PSLR test. Thus, the difference between both angles is 31.3° and 19.4° in the T_PSLR and N_PSLR test respectively. Therefore, there is a significant difference of 11.91° between both procedures (38.7° ± 12.5° vs. 26.8° ± 12.5°; d = −0.952 [moderate]) (Table 2).

Figure 4 summarizes the differences between both procedures.

Male and female results for PSLR variables, pelvis tilt and lumbar lordosis are presented in Tables 3 and 4, respectively.

Table 2. Results of hamstring extensibility, pelvis tilt and lumbar lordosis (in degrees) for the sex-combined (total) sample according to type of procedure (traditional procedure vs. new procedure).

	T_PSLR	**N_PSLR**	**Difference Average**	***p*-Value**	**d-Value (Qualitative Inference)**
PSLR (° *)	89.2 ± 20.8	75.3 ± 14.4	13.9 ± 9.5	0.000	Moderate (d = −0.777)
PT _ neutral position (°)	42.2 ± 9.6	42.2 ± 9.6			
PT _ PSLR (°) *	18.7 ± 9.5	27.5 ± 8.5	8.78 ± 5.18	0.000	Moderate (d = 0.976)
LL _ neutral position (°)	58.1 ± 13.8	58.1 ± 13.8			
LL_ PSLR (°) *	26.8 ± 12.5	38.7 ± 12.5	−11.91 ± 8.44	0.000	Moderate (d = 0.952)

Values expressed in degrees as mean ± standard deviation; °: degrees; T_PSLR: traditional passive straight leg raise; N_PSLR: new passive straight leg raise; LL: angle of lumbar lordosis; PT: angle of pelvic tilt; d-value: values of effect sizes of Cohen in qualitative inference. * significant at $p \leq 0.05$ (nonparametric Mann-Whitney U test; **: The correlation is significant at the level 0.01 (bilateral).

Table 3. Results of hamstring extensibility, pelvis tilt and lumbar lordosis (in degrees) for males according to type of procedure (traditional procedure vs. new procedure).

	T_PSLR	**N_PSLR**	**Difference Average**	***p*-Value**	**Qualitative Inference**
PSLR (degrees) *	79.4 ± 11.2	68.0 ± 11.0	11.4 ± 6.3	0.005	Moderate (d = −1.027)
PT _ neutral position (degrees)	44.1 ± 11.6				
PT _ PSLR (degrees) *	17.7 ± 11.7	27.5 ± 11.5	9.80 ± 5.0	0.005	Moderate (d = 0.845)
LL _ neutral position (degrees)	57.6 ± 15.6				
LL_ PSLR (degrees) *	24.7 ± 13.3	38.4 ± 16.8	-13.7 ± 9.4	0.005	Moderate (d = 0.904)

* Values expressed in degrees as mean ± standard deviation; T_PSLR: traditional passive straight leg raise; N_PSLR: new passive straight leg raise; LL: angle of lumbar lordosis; PT: angle of pelvic tilt; d-value: values of effect sizes of Cohen in qualitative inference. Significant at $p \leq 0.05$ (nonparametric Wilcoxon signed-rank test).

Table 4. Results of hamstring extensibility, pelvis tilt and lumbar lordosis (in degrees) for females according to type of procedure (traditional procedure vs. new procedure).

	T_PSLR	**N_PSLR**	**Difference Average**	***p*-Value**	**Qualitative Inference**
PSLR (degrees) *	96.8 ± 23.6	80.9 ± 14.5	15.8 ± 11.2	0.001	Moderate (d = −0.812)
PT _ neutral position (degrees)	40.7 ± 8.0				
PT _ PSLR (degrees) *	19.5 ± 7.9	27.5 ± 5.9	8.00 ± 5.4	0.003	Moderate (d = 1.147)
LL _ neutral position (degrees)	58.5 ± 12.9				
LL_ PSLR (degrees) *	28.5 ± 12.1	39.0 ± 8.7	−10.5 ± 7.7	0.002	Moderate (d = 0.996)

* Values expressed in degrees as mean ± standard deviation; T_PSLR: traditional passive straight leg raise; N_PSLR: new passive straight leg raise; LL: angle of lumbar lordosis; PT: angle of pelvic tilt; d-value: values of effect sizes of Cohen in qualitative inference. Significant at $p \leq 0.05$ (nonparametric Wilcoxon signed-rank test).

Table 5 shows the Spearman correlation coefficients for sex-combined (total) sample. The results showed a high relationship between both procedures of PSLR test (r = 0.877; p = 0.000). In the radiographic parameters, the results showed a high correlation between the pelvis tilt in the new PSLR test and the lordosis curve in the new PSLR test (r = 0.801; p = 0.000) and between the pelvis tilt in the traditional PSLR test and the lordosis curve in the traditional PSLR test (r = 0.849; p = 0.000). However, the results showed a low relationship between both procedures of PSLR test (traditional or new) and the pelvic tilt and the angle of lordosis lumbar.

All variables that displayed significant relationships to PSLR (traditional or new procedure, pelvis tilt and lumbar lordosis) also demonstrated significant R^2 values, suggesting that these metrics may be predictive of PSLR. Regression equations for each variable can be found in Table 1; individual data plots for each variable with accompanying regression lines are depicted in Figure 5A–E.

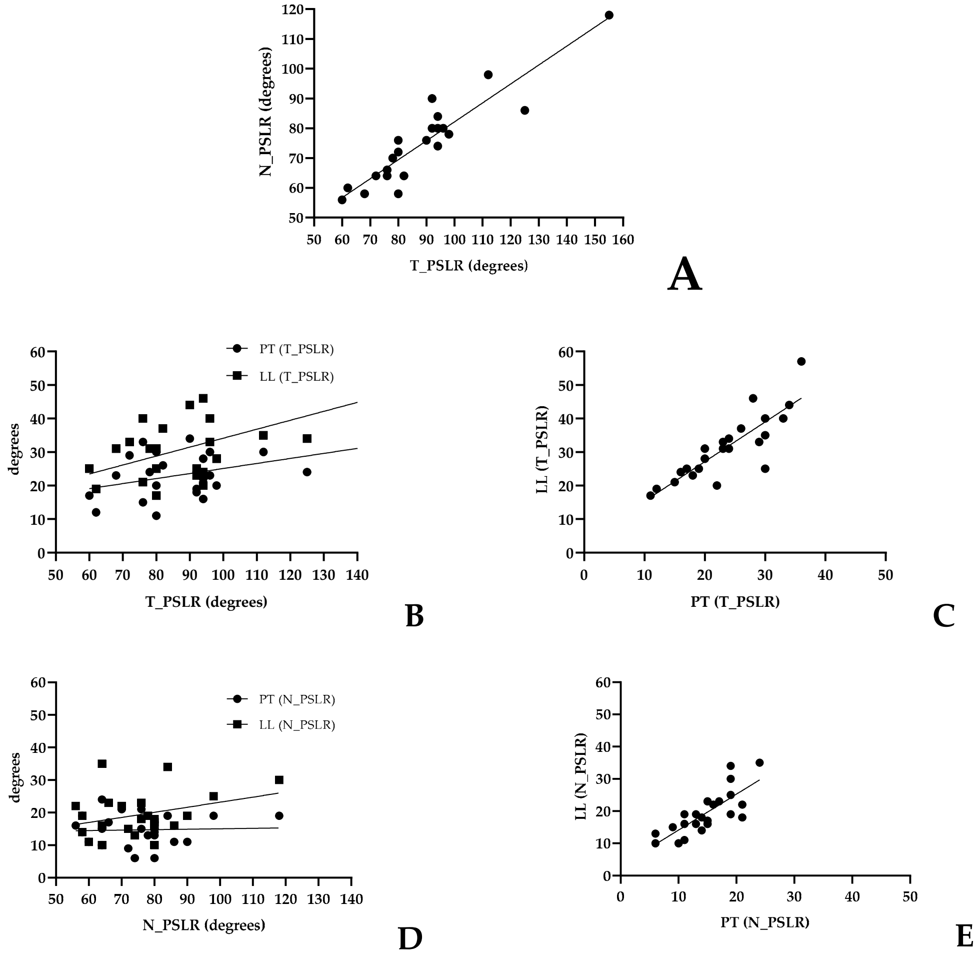

Figure 5. Individual data points and accompanying nonlinear regression lines for both PSLR procedure, traditional and new (**A**), traditional PSLR procedure and PT and LL (**B**), PT and LL in PSLR traditional procedure (**C**), new PSLR procedure and PT and LL (**D**) and PT and LL in PSLR new procedure (**E**).

Finally, the results of the nonlinear regression procedure do not allow us to make an accurate prognosis of the angle of pelvic tilt and angle of lordosis lumbar obtained through either PSLR because scores below or equal to 2.9% and 3.8% of the explained variance were found for both traditional ($p \geq 0.220$) and new ($p \geq 0.275$) procedure, respectively. Therefore, it is not considered appropriate to use the regression formulas resulting from this statistical analysis to calculate the angle of pelvic tilt and the angle of lordosis lumbar trough the final score in both procedures of PSLR test (Table 4).

Table 5. Coefficients between PSLR (traditional and new procedures) and pelvic tilt (PT) and lumbar lordosis (LL) angles. Ninety percent confidence intervals (90% CI), *p* values and magnitude descriptors are also shown. Variance explained (R^2) and the nonlinear regression equations are presented for each variable.

Tests		Correlation	90% CI			*p* Value	Descriptor	R^2	Regression Equation
T_PSLR	N_PSLR	**0.877**	0.704	to	0.956	0.000	Very large	**0.8445**	T_PSLR= 18.53 + 0.6363*N_PSLR
T_PSLR	PT (T_PSLR)	0.324	0.160	to	0.659	0.132	Small	0.1987	T_PSLR = 10.09 + 0.1501*PT_T_PSLR
	LL (T_PSLR)	0.382	0.046	to	0.672	0.072	Small	0.3236	T_PSLR = 7.457 + −0.2668*LL_T_PSLR
	PT vs. LL (T_PSLR)	**0.863**	0.648	to	0.975	0.000	Very large	**0.7206**	LL_T_PSLR= 3.504 + 1.182*PT_T_PSLR
N_PSLR	PT (N_PSLR)	−0.059	0.467	to	0.332	0.788	Small	**0.0017**	N_PSLR = 13.65 + 0.01385*PT_N_PSLR
	LL (N_PSLR)	0.236	0.234	to	0.625	0.279	Moderate	0.1082	N_PSLR = 7.622 + 0.1557*LL_N_PSLR
	PT vs. LL (N_PSLR)	**0.801**	0.543	to	0.916	0.000	Very large	**0.6075**	LL_N_PSLR= 2.993 + 1.113*PT_N_PSLR

T_PSLR: traditional passive straight leg raise; N_PSLR: new passive straight leg raise; Rx: angles measured on the radiography; LL: angle of lumbar lordosis; PT: angle of pelvic tilt.

4. Discussion

The main objective of the present study was to evaluate the influence of the Lumbosant© and an assistant examiner on scores obtained in the assessment of hamstring extensibility through PSLR test in healthy young adults. A secondary objective was to verify the variability of the retroversion movement of posterior pelvis tilt and a simultaneous decrease in lumbar lordosis after the application of the PSLR test in healthy young adults.

The initial hypothesis was that when the traditional PSLR is performed (T_PSLR), a posterior pelvic tilt movement occurs and lumbar lordosis decreases, which implies that the traditional PSLR overestimates the hamstring extensibility. Conversely, using a low-back protection support (Lumbosant©) and a trained auxiliary test administrator (N_PSLR), the score will be more sensitive as the compensatory movements will decrease. These data are important, as the PSLR test is one of the most commonly performed tests in clinical practice.

The results of the current study show that the score reached with the new version of the PSLR is always lower than the score reached with the traditional version. Thus, in the clinical assessment of hamstrings extensibility (measurement with inclinometer), when the Lumbosant© and the assistant examiner are used, the score is 13.9° lower than in the traditional procedure. Similarly, the changes in the pelvis posterior tilt (23.5° versus 14.7° in the T_PSLR and N_PSLR test, respectively) and the lordosis lumbar angle (31.3° and 19.4° in the T_PSLR and N_PSLR test, respectively) are higher with the traditional PSLR test. The inclination of the pelvis (posterior tilt) and the lumbar curvature angle were set as the angle change amount from the test start position to the end of the final test in both tests.

This difference between measurements of increases in the PSLR angle and increases in the pelvis angle is important in the interpreting clinical and research results. Unless the pelvis will be completely stabilized, measurements of PSLR do not give a true indication of hamstring extensibility.

Previous literature has highlighted the role of pelvic retroversion on hamstrings extensibility. In his first study, Bohannon [53] found that increases in the angle of SLR concerning the horizontal were found to be greater than increases in the angle of SLR concerning the pelvis. His work states that 1° of pelvic rotation allows a 3.27–3.42° increase in the angle of the pelvis measured with the SLRP in three different ways of strapping the thigh and/or pelvis.

In a second study, Bohannon et al. [54] found that each 2.7° of SLRP/horizontal angle was accompanied by 1.7° of the SLRP/pelvis angle and 1° of the pelvic rotation/horizontal angle. Additionally, they found that the ratio of the PSLR/horizontal angle to pelvis/horizontal angle decreased from the first one-third to the third one-third of the ROM. Thus, the relative contribution of pelvic rotation to the PSLR/horizontal angle increased as the angle of PSLR increased. Pelvic rotation occurred in every subject by the time the lower limb reached 9 degrees with the horizontal plane and usually began before the PSLR/horizontal angle increased 4 degrees. The mean slope of the simple linear regression line of measurements of increases in the PSLR/horizontal angle and increases in the pelvis/horizontal angle determined for each subject was 0.39 (range, 0.30–0.46). The correlations between the increases in the PSLR/horizontal angle and pelvis/horizontal angle for each subject ranged from 0.977 to 0.995 (mean 0.990).

Another interesting finding reported by Bohannon et al. [43] was that although their expectation was that the contribution of the pelvis/horizontal angle would occur late in the PSLR motion, pelvic rotation began almost as soon as PSLR began. It is necessary to take into account that in this study the PSLR was performed by a single examiner and without lumbar support. Perhaps, for that reason, it is so important to use a lumbar support to fix the pelvis.

Previous studies have used different strategies to fix the pelvis in a neutral or standardized position during SLR. Milne and Mierau [55] suggest holding both anterior superior iliac spines through an assistant examiner. Bohannon [53], Ekstrand et al. [56], Cameron and Bohannon [57] and Gajdosik et al. [58] suggested using straps to fix the pelvis. Another strategy proposed has been to stop the test when observing the beginning of pelvic tilt [59] or to stop the test when observing a decrease in lumbar lordosis [6,41,60]. Other authors modified the starting position of the pelvis by placing it in an initial retroversion or modify the starting position of the hip [41,57,61]. The objective is to minimize pelvic tilt and thus substantively reduce compensatory movements and obtain a more specific test result for assessment hamstring extensibility.

Other authors have used a lumbar support to homogenize the position of the pelvis and lumbar curvature in a neutral or standardized position. Thus, in the literature, we can find different types of support, such as a pillow or a towel [53,54,62] or different rigid lumbar supports for placing under the lumbar zone [9,63,64]. The first lumbar support that was used was the "BackMate" back rehabilitation device. This system incorporated a pelvic stabilization device (using a belt to secure and stabilize the pelvis) that isolated the lumbar muscles during the exercises [64]. The second was the Lumbosant©, a low-back protection rigid support designed by Santonja to maintain and protect the normal lumbar curvature [9], and the third was the "MacReflex measurement system" [63]. The "Backmate" and "MacReflex measurement system" are flat lumbar supports, while the Lumbosant© is a rigid support that has a normal lordotic curvature (Figure 2). However, although all of those lumbar supports were designed to stabilize the pelvis, the degree of stabilization or the involvement of the pelvis and lumbar curvature in the actual measurement of hamstring extensibility has not been quantified.

Radiography seems to be the best criterion measurement (gold standard) to assess hamstring muscle flexibility [29,37,65] and to determine the effects of hamstring lengthening on sagittal spinal curvatures and pelvic tilt. However, because of its high cost and the need for sophisticated instruments, qualified technicians, exposure to ionizing radiation, limited portability and time constraints, the use of this method is limited in scientific, clinical, sports and physical therapy settings [66].

To the best of our knowledge, the current study is the first to analyze and compare two different PSLR test through X-ray. The results show a high relationship between both procedures of the PSLR test (p = 0.000; r = 0.877). In the radiographic parameters, the results show a high correlation between the pelvis tilt measurement in both procedures (p = 0.000; r = 0.841) and between the pelvis tilt and the lordosis curve in both tests (N_PSLR; p = 0.000, r = 0.868; T_PSLR; r = 0.880, p = 0.000).

However, the nonlinear regression formula predicts only a 3.8% maximum success rate for the PSLR result across the angle of pelvic tilt and the angle of lumbar curvature. The individual analysis shows that pelvic tilt occurs in all cases (traditional procedure: range 11° to 36°; new procedure: range 6° to 24°), regardless of the degree of hamstring extensibility in the traditional and new procedure, respectively; these results shows that the pelvis always tilts and this tilting movement is variable among individuals. The angle of lumbar curvature in both positions also behaves similarly to the pelvic tilt angle (traditional procedure: range between 10° to 57°; new procedure: range between 10° to 35°), since it undergoes a reduction of 53.8% (58.1° to 26.8°) and 33.3% (58.1° to 38.7°) in the traditional and new procedure, respectively.

In the present study, a slightly lower average score has been found (4.07° + 1.23°), that is to say, 1° out of 4° in the PSLR test final score is produced thanks to the pelvis rotation. However, the results also showed a moderate inter-individual variability (from 2.3° to 7.3°) for the amount of the pelvis contribution to the final score in the PSLR test. When the percentage value of involvement of the pelvis in the PSLR test is analyzed, it ranges from 13.7% to 43.4%, which may demonstrate that an average approximation should not be made due to its inaccuracy.

The use of the low back protection support reduced almost 50% of the pelvis rotation motion observed during the PSLR test, whereby it reduced nearly 1° out of 7° of the anterior pelvic tilt motion occurred during the PSLR test. This finding also supports the use of this low back protection support. The data presented in this study suggest that the PSLR is not a valid measure of hamstring extensibility unless lumbopelvic movement is controlled. Compensatory movement based on pelvic retroversion during the test may therefore mask hamstrings shortening. Therefore, we recommend the use of Lumbosant© and an auxiliary examiner to obtain more precise results.

Several limitations are present that could be addressed in future studies to complement the knowledge about this topic. First, to determine the specific level of uncomfortable sensation in the hamstring muscle during the passive tests, a visual analog pain scale could be used [67]. Second, to determine the involvement of several muscles in the tests used, an electromyography system could be implemented. Third, a small sample was used, but this is often something that cannot be overcome when X-ray assessment is used. Moreover, in the current study, the validity was examined only in a population of young, sedentary and healthy adults. Further studies in other populations with limited hamstring extensibility or pathology are, therefore, necessary.

5. Conclusions

During the execution of the PSLR test, a posterior pelvic tilt movement is always observed and its magnitude does not seem to be associated with the hamstring extensibility. Likewise, lumbar lordosis is always proportionally reduced to the degree of posterior pelvic tilt motion but this is not associated with the hamstring extensibility score. Lower back protection support may be an effective tool to reduce the pelvis tilt and to minimize the reduction in the lumbar lordosis observed during the PSLR test maneuver. The only sex-related differences were found in the hamstring extensibility measure obtained through the PSLR test, independently of the version (traditional and new). Therefore, the results of the current study suggest that the PSLR may overestimate the hamstring extensibility unless lumbopelvic movement is controlled. Therefore, we recommend the use of Lumbosant© and an auxiliary examiner to obtain more precise results.

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