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Criterion-Related Validity of Sit-and-Reach and Toe-Touch Tests as a Measure of Hamstring Extensibility in Athletes

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Abstract

Muyor, JM, Vaquero, R, Alacid, F, and López-Miñarro, PA. Criterion-related validity of sit-and-reach and toe-touch tests as a measure of hamstring extensibility in athletes. *J Strength Cond Res* XX(X): 000–000, 2013—The aims of this study were (a) to determine and compare the concurrent hamstring criterion-related validity of the sit-and-reach (SR) and toe-touch (TT) tests in different athletes (tennis players, kayakers, canoeists, and cyclists); (b) to determine the criterion-related validity of the pelvic tilt assessed by the Spinal Mouse system as a measure of hamstring flexibility in athletes; and (c) to evaluate the influence of spinal posture, pelvic tilt, and hamstring muscle flexibility in the SR and TT scores. Twenty-four tennis players, 30 canoeists, 43 kayakers, and 44 cyclists were recruited. Passive straight leg raise (PSLR), SR, and TT tests were randomly performed. Spinal curvatures and pelvic tilt were evaluated with a Spinal Mouse system when the maximal trunk flexion was achieved in the SR and TT tests. Tennis players and cyclists showed moderate correlations between PSLR with respect to SR ($\beta = 0.78$ and $\beta = 0.76$, respectively) and TT ($\beta = 0.77$ and $\beta = 0.74$, respectively). Correlations were slightly lower in canoeists (SR, $\beta = 0.64$; TT, $\beta = 0.75$). Kayakers showed the lowest correlation values (SR, $\beta = 0.53$; TT, $\beta = 0.57$). Correlation values between PSLR and pelvic tilt angle in both the SR and TT tests were $\beta < 0.70$ in all the groups of athletes. Stepwise multiple regression analysis showed a high variance explained from pelvic tilt and lumbar spine in the SR score. In conclusion, the SR and TT tests can be appropriate measures to determine spine flexibility and pelvic tilt range of motion but not to evaluate the hamstring muscle flexibility in tennis players, canoeists, kayakers, and cyclists.

Key Words flexibility, posture, spinal curvatures, muscle

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Journal of Strength and Conditioning Research

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Introduction

Hamstring flexibility has been analyzed in recent years because it is an important component of physical fitness and spinal health. Decreased flexibility has been associated with hamstring muscle injuries (8), changes in lumbopelvic rhythm (13), greater thoracic kyphosis during maximal trunk flexion movements (14), lower back pain (5), spondylolysis and spondylolisthesis (38), and a less economical energy efficient in muscles and tendons during the stretch-shortening cycle (39). For these reasons, an AU3 evaluation of hamstring flexibility is a common component of sport training.

To determine hamstring muscle flexibility, some methods have been proposed. The sit-and-reach (SR) and toe-touch (TT) tests have frequently been used in sports settings because the procedure is simple, easy to administer, and requires minimal skills training. However, these tests are considered like indirect measures of hamstring flexibility because the score reached is the result of several factors such as hip flexibility (10), anthropometric dimensions (16,37), test procedures (28), and spinal flexibility (37).

Therefore, several studies have analyzed the validity of the SR and the TT tests and reported from low to moderate correlation values (between $r = 0.44$ and $r = 0.76$) with respect to the passive straight leg raise (PSLR) test, which is considered as the gold standard for hamstring flexibility (1,2,4,9,10,17,18,23–25,29,34,36). However, most of these studies included sedentary population, and studies involving athletes are more limited. In these sense, Ayala et al. (1) found a high correlation ($r = 0.80$) between PSLR and SR in futsal players. López-Miñarro et al. (24) found correlation values between PSLR and SR ($r = 0.75$) and between PSLR and TT ($r = 0.69$) in young paddlers.

On the other hand, to avoid the influence of anthropometric variables when maximal trunk flexion with knees extended is performed, some studies have evaluated the lumbopelvic posture in the SR score (3,12,22,31). Other studies have determined the validity of the sacral angle without the implication of lumbar posture (referred to as the pelvic posture) as a measure of hamstring flexibility during the SR and TT tests (2,11). In fact, recently, the SR test has been recommended as a more accurate representation of pelvic flexibility than the hamstring muscle flexibility (12). To determine pelvic posture, goniometers, inclinometers, or video analyses have been used. However, in recent years, the Spinal Mouse, a computer hand-held computer, has been used to evaluate spinal postures and pelvic inclination in different positions. Although, the validity of pelvic position, measured with this system as a measure of hamstring flexibility, has not been examined.

Also, because the particular postures and movements of each sport have been associated with specific adaptations in sagittal spinal curvatures (40), it could influence the hamstring criterion-related validity of the SR and TT tests to evaluate the hamstring flexibility. Because the score reached in the SR and TT tests is influenced by the spinal curvatures (9,37), it is considered necessary to evaluate the validity of the SR and TT tests to evaluate the hamstring flexibility with regard to the sport discipline and their spinal adaptations.

Therefore, the objectives of this study were (a) to determine and compare the concurrent validity of the SR and TT tests in different groups of athletes (tennis players, kayakers, canoeists, and cyclists); (b) to determine the criterion-related validity of the pelvic tilt assessed by the Spinal Mouse system as a measure of hamstring flexibility in these athletes; and (c) to evaluate the AU4 influence of spinal parameters and/or hamstring muscle flexibility in the SR and TT scores. We hypothesized that the validity of the SR and TT tests would be different among kayakers, canoeists, tennis players, and cyclists as a result of spinal adaptations to their postures and movements performed during training and competitions. Furthermore, pelvic inclination will not be a reliable measure to determine the hamstring flexibility in these groups of athletes. We also hypothesized that the pelvic tilt would have a great influence on the score achieved during the SR and TT tests.

Methods

Experimental Approach to the Problem

The primary focus of this study was to determine the criterion-related validity of SR and TT tests as a measure of hamstring flexibility with respect to sport discipline. Several sport disciplines were chosen in relation to their different movements and postures during training and competition. A descriptive-correlational design was used to determine and compare the concurrent validity of the SR and TT tests and pelvic tilt in different athletes, using the PSLR test as a measure criterion of hamstring muscle flexibility. The PSLR has frequently been used in multiple studies as a criterion measure (gold standard) of hamstring flexibility (1,2,19,22–24,27). Because the SR and TT scores are affected by the spinal parameters (thoracic and lumbar spine) and pelvic posture, the spinal curvatures and pelvic tilt were determined in both the SR and TT tests when maximal trunk flexion was reached using a Spinal Mouse system (Idiag, Fehraltdorf, Switzerland), a hand-held computer-assisted electromechanical-based device. To determine the influence of spinal parameters on the score achieved during the SR and TT tests, a stepwise multiple regression analysis was performed.

Subjects

One hundred forty-one young male athletes (24 tennis players, 30 canoeists, 43 kayakers, and 44 cyclists) participated in this study (Table 1). Inclusion criteria were (a) at least 4 years of training experience; (b) training between 3 and 6 $d \cdot wk^{-1}$; and (c) daily training from 2 to 4 hours. The athletes were excluded if they suffered pain induced or exacerbated by the test procedures, had an injury preventing participation in training before testing, or had known structural spinal pathology. All the participants were instructed to avoid strenuous training and physical activity 24 hours before the study. T1

An Institutional Ethical Committee at the University of Murcia approved the study. All children's parents or tutors and the subjects who participated in this study were informed of the procedures and signed a consent form before the measurements were made.

Procedures

Hamstring muscle flexibility was determined in both legs using the PSLR, the SR, and the TT scores. Sagittal spinal curvatures (thoracic and lumbar curvatures) and pelvic tilt were measured when maximal trunk flexion was achieved in the SR and TT tests using a Spinal Mouse system (Idiag). The Spinal Mouse is an electronic computer-aided measuring device, which measures the sagittal spinal range of motion and intersegmental angles in a noninvasive way, a so-called surface-based technique. The device is connected radiographically via an analog-digital converter to a standard PC. For global spinal angles, the Spinal Mouse has proved to be a valid and reliable device (14,32). No warm-up or stretching exercises were performed by the subjects before the test measurements. The participants were examined wearing underwear and barefoot. The measurements were performed in a random order. There was

Table 1. Characteristics of the athletes.

	n	Age (y)	Height (cm)	Body mass (kg)
Tennis players	24	15.75 ± 1.42	174.92 ± 10.08	67.20 ± 10.93
Canoeists	30	15.03 ± 0.76*	173.07 ± 5.52	69.24 ± 8.15
Kayakers	43	15.51 ± 0.91*	173.69 ± 5.76	68.10 ± 9.68
Cyclists	44	17.84 ± 0.93	177.91 ± 6.25	69.17 ± 9.37

*$p < 0.001$ in cyclists.

a 5-minute rest between measures. All the measurements were performed between 1000 and 1400 hours, during 4 weeks. The laboratory temperature was standardized at 24° C.

Passive Straight Leg Raise Test. The PSLR test (left and right legs) was conducted in a counterbalanced order. The subjects were placed in a supine position with the lower extremities in 0° hip flexion. While the participant was in the supine position, a Uni-Level inclinometer (Isomed, Inc., Portland, OR, USA) was placed over the distal tibia to measure the inclination. A lumbar protection support (Lumbosant; Murcia, AU5 Spain) was used to maintain a neutral lumbar lordosis during the test (34). Thereafter, the participant's leg was lifted passively by the tester into a hip flexion. The knee remained straight during the leg raise, whereas the pelvis and the other leg were fixed by an assistant tester to avoid posterior pelvic F1 tilt (1) (Figure 1). The end point for the straight leg raise (SLR) was determined by 1 or both criteria: (a) the participants reported pain in hamstring muscle and/or (b) palpable onset of pelvic rotation. Moreover, the ankle of the tested leg was restrained in maximum plantar flexion to avoid adverse neutral tension.

Sit-and-Reach Test. The participants were required to sit on the floor with the knees straight, legs together, and the soles of the feet positioned flat against an SR box (Acuflex I Flexibility Tester, height: 32 cm; Psymtec, Madrid, Spain). A standard meter rule was placed on the SR box, with a 0-cm mark representing the point at which the subjects' fingertips were in line with their toes. With palms down, the participants placed the dominant hand on top of the other and were asked to bend forward as far as possible sliding their hands along the box, keeping their knees extended, and holding the position of maximal flexion for approximately 5 seconds while the spinal curvatures and pelvic inclination were measured with the Spi-F2 nal Mouse system (Figure 2).

Figure 1. Hamstring flexibility measured during the passive straight leg raise test. AU12

Figure 2. Spinal curvatures and pelvic tilt measured during the sit-and-reach test.

Toe-Touch Test. The participants were placed in the standing position on the SR box, with the knees extended and fixed by a tester, and the feet spread to the width of their hips. A standard meter rule was placed on the SR box with a 0-cm mark representing the point at which the subjects' fingertips were in line with their toes. From this position, the subjects

Figure 3. Spinal curvatures and pelvic tilt measured during the toe-touch test.

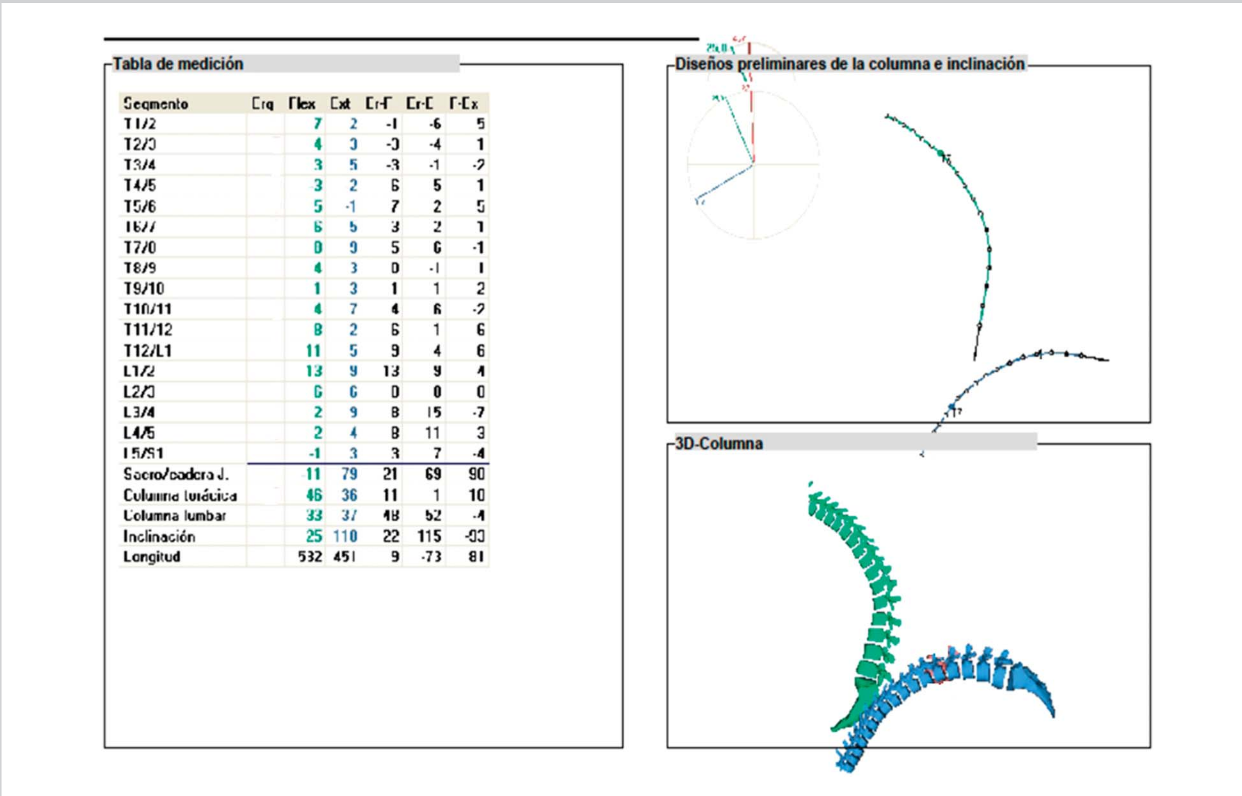

Figure 4. Spinal and pelvic angles generated with MediMouse software.

were asked to bend forward as far as possible, sliding their hands along the box to reach the maximal distance, and holding the position for approximately 5 seconds while the spinal curvatures and pelvic inclination were measured with the Spinal Mouse system (Figure 3).

F3

Spinal Curvatures and Pelvic Tilt Measurements. Before measurements, the main researcher determined the spinous processes of C7 (starting point) and the top of the anal crease (end point) by palpation, and marked these points on the skin with a pencil. Once the athlete reached the maximal

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TABLE 2. Mean ± *SD* in the different tests between kayakers, canoeists, tennis players, and cyclists.*

Test	Tennis players ($n = 24$)	Canoeists ($n = 30$)	Kayakers ($n = 43$)	Cyclists ($n = 44$)
Right PSLR (°)	71.75 ± 10.37†	76.07 ± 14.15	82.23 ± 10.43	75.07 ± 9.32‡
Left PSLR (°)	67.67 ± 10.17	75.67 ± 10.68§	82.51 ± 9.04‖	75.50 ± 8.76§
SR (cm)	−4.87 ± 9.82	−1.30 ± 7.49‡	4.98 ± 6.22‖	−0.50 ± 10.32‡
TT (cm)	−8.63 ± 9.68	−4.53 ± 8.40†	0.81 ± 7.38‖	−3.98 ± 10.87†
Thoracic angle SR (°)	57.38 ± 7.78	61.03 ± 10.41	56.72 ± 11.08	64.27 ± 10.55†
Lumbar angle SR (°)	30.67 ± 9.99	31.17 ± 8.04	33.09 ± 6.60	34.16 ± 7.25
Pelvic tilt SR (°)	−17.08 ± 9.29	−16.10 ± 8.64	−9.65 ± 8.43	−15.23 ± 10.53
Thoracic angle TT (°)	52.46 ± 6.88	54.73 ± 6.99	50.77 ± 8.51	54.43 ± 9.03
Lumbar angle TT (°)	32.42 ± 8.62	33.87 ± 8.26	33.19 ± 6.57	36.00 ± 9.94
Pelvic tilt TT (°)	64.29 ± 12.41	65.67 ± 11.99	71.95 ± 11.14	62.93 ± 11.73†

*PSLR = passive straight leg raise test; SR = sit-and-reach test; TT = toe-touch test.
†$p < 0.01$ with respect to kayakers.
‡$p < 0.05$ with respect to kayakers.
§$p < 0.05$ with respect to tennis players.
‖$p < 0.001$ with respect to tennis players.

trunk flexion position, the Spinal Mouse was guided along the midline of the spine (or slightly paravertebrally in particularly thin individuals with prominent spinous processes) starting at the spinous process of C7 and finishing at the top of the anal crease (ca., S3). The MediMouse software recorded the thoracic (T1-2 to T11-12) and lumbar (T12-L1 to the sacrum) spine and the pelvic tilt values (difference F4 between the sacral angle and the vertical plane) (Figure 4). Each measurement was repeated twice within a 5-minute rest. The average of the 3 trials was used for data analysis. Each subject was measured on the same day. For the lumbar curve, negative values corresponded to lumbar lordosis, and positive values corresponded to lumbar kyphosis. With respect to the pelvic position in the SR test, a value of 0° represented the vertical plane position. In the TT test, a value of 90° corresponded to a horizontal plane position in the TT test. Thus, a greater angle (positive values in the SR test) reflected an anterior pelvic inclination and a lower angle (negative values in the SR test) reflected a posterior pelvic inclination.

Statistical Analyses

Intratester reliability of thoracic and lumbar curvatures and pelvic tilt was calculated in a previous pilot study. Twenty subjects who did not participate in the final sample of this study were measured 3 times by the same tester in a standing position, slumped sitting, and prone lying. Intraclass correlation coefficients (ICCs) with 95% confidence intervals (CIs) were calculated. An ICC ≥0.98 (95% CI, 0.98–0.99) was obtained for thoracic kyphosis, lumbar lordosis, and pelvic tilt in all the postures evaluated. Moreover, the intratester reliability of the PSLR test was also calculated. Both legs were measured 3 times by the same tester. The ICCs with 95% CI were calculated. An ICC ≥ 0.91 (95% CI, 0.90–0.99) was obtained for the left and right legs. The intraexaminer *SEM* ranged from 1.20° to 0.16° for both legs (30,31).

The hypothesis of normality was analyzed via the Kolmogorov-Smirnov test. Parametric analysis was performed because the data were normally distributed. Descriptive statistics including means and standard deviations were calculated. A 1-way analysis of variance was used to identify the differences among the groups of athletes. Significant F-ratios were followed by the Bonferroni post hoc analysis to examine pairwise group differences. A paired *t*-test was used to compare the SLR values between both legs in each group. The average between the right and left leg angles was used for subsequent validity analysis. Bivariate correlation analysis and multiple

Table 3. Standardized multiple regression coefficients (β), 95% CI, *SE*, and R^2 examining the association among SR, TT, and average (left, right legs) PSLR in tennis players, canoeists, kayakers, and cyclists.*

	β	95% CI	*SE*	R^2	*p*
Tennis players (n = 24)					
SR vs. PSLR	0.78	0.50–1.05	0.13	0.60	<0.001
TT vs. PSLR	0.77	0.50–1.07	0.13	0.60	<0.001
Pelvic tilt SR vs. PSLR	0.60	0.26–1.01	0.18	0.36	<0.01
Pelvic tilt TT vs. PSLR	0.66	0.26–0.78	0.12	0.44	<0.001
Pelvic tilt SR vs. pelvic tilt TT	0.89	0.51–0.81	0.07	0.79	<0.001
Canoeists (*n* = 30)					
SR vs. PSLR	0.64	0.52–1.43	0.22	0.41	<0.001
TT vs. PSLR	0.75	0.66–1.34	0.16	0.56	<0.001
Pelvic tilt SR vs. PSLR	0.59	0.37–1.18	0.19	0.35	0.001
Pelvic tilt TT vs. PSLR	0.71	0.41–0.92	0.12	0.50	<0.001
Pelvic tilt SR vs. pelvic tilt TT	0.81	0.42–0.74	0.08	0.65	<0.001
Kayakers (*n* = 43)					
SR vs. PSLR	0.53	0.39–1.19	0.19	0.28	<0.001
TT vs. PSLR	0.67	0.33–1.01	0.16	0.28	<0.001
Pelvic tilt SR vs. PSLR	0.56	0.34–0.91	0.14	0.32	<0.001
Pelvic tilt TT vs. PSLR	0.56	0.25–0.68	0.10	0.31	<0.001
Pelvic tilt SR vs. pelvic tilt TT	0.86	0.53–0.77	0.60	0.74	<0.001
Cyclists (*n* = 44)					
SR vs. PSLR	0.76	0.47–0.94	0.11	0.58	<0.001
TT vs. PSLR	0.74	0.44–0.93	0.93	0.54	<0.001
Pelvic tilt SR vs. PSLR	0.67	0.40–0.98	0.14	0.45	<0.001
Pelvic tilt TT vs. PSLR	0.53	0.16–0.70	0.13	0.28	<0.01
Pelvic tilt SR vs. pelvic tilt TT	0.78	0.52–0.87	0.08	0.60	<0.001

*SR = sit-and-reach test; PSLR = passive straight leg raise test; TT = toe-touch test.

regressions were used to analyze the concurrent validity among the SR, TT, and PSLR tests.

The Bland-Altman plot was used to analyze the agreement between the SR and TT scores (7). Stepwise multiple regression analysis was performed to identify the spinal parameters that influence the score reached in the SR and TT tests. The level of significance was set at $p \leq 0.05$. Data were analyzed using the Statistical Package for Social Sciences (version 18.0; SPSS, Inc., Chicago, IL, USA).

Results

The mean values of the PSLR, SR, TT, sagittal spinal curvatures, and pelvic tilt are presented in Table 2. The kayakers showed the highest values in the PSLR, SR, and TT scores, followed by the canoeists and the cyclists. Tennis players had the lowest values in all the tests and showed significant differences between the right and left values in the PSLR ($p < 0.01$). Regarding pelvic position, the kayakers showed the highest pelvic tilt values in the SR test, followed by the cyclists, the canoeists, and the tennis players. In the TT test, the pelvic tilt was higher in kayakers, whereas the cyclists showed the lowest values.

The multiple regression analysis examining the association among tests is shown in Table 3. The highest regression coefficients were found between the pelvic tilt angle in the SR and TT tests ($\beta = 0.78–0.89$). Tennis players and cyclists showed a moderate association between PSLR and SR and TT scores ($\beta = 0.74–0.78$). The variance explained between these tests was low ($R^2 = 0.54–0.60$). Canoeists and kayakers showed a lower association between PSLR with respect to the SR and TT tests ($\beta = 0.53–0.75$). The pelvic tilt angle in the SR and TT tests showed low to moderate association with the PSLR test in all the groups (Table 3). The Bland-Altman plot analysis between pelvic tilt angles in the SR and TT tests showed that the differences between them were not proportional to the mean in all the groups (Figure 5).

Table 4 shows the stepwise multiple regression analysis to determine which variables in relation to hamstring muscle flexibility and spinal curvatures influence the SR and TT scores. Pelvic tilt and lumbar spine contributed to the greater explanation of distance reached in all groups. Only in tennis players and cyclists was the hamstring muscle flexibility in PSLR included in the model, which explained the 31% in tennis players and the 1.6% in cyclists.

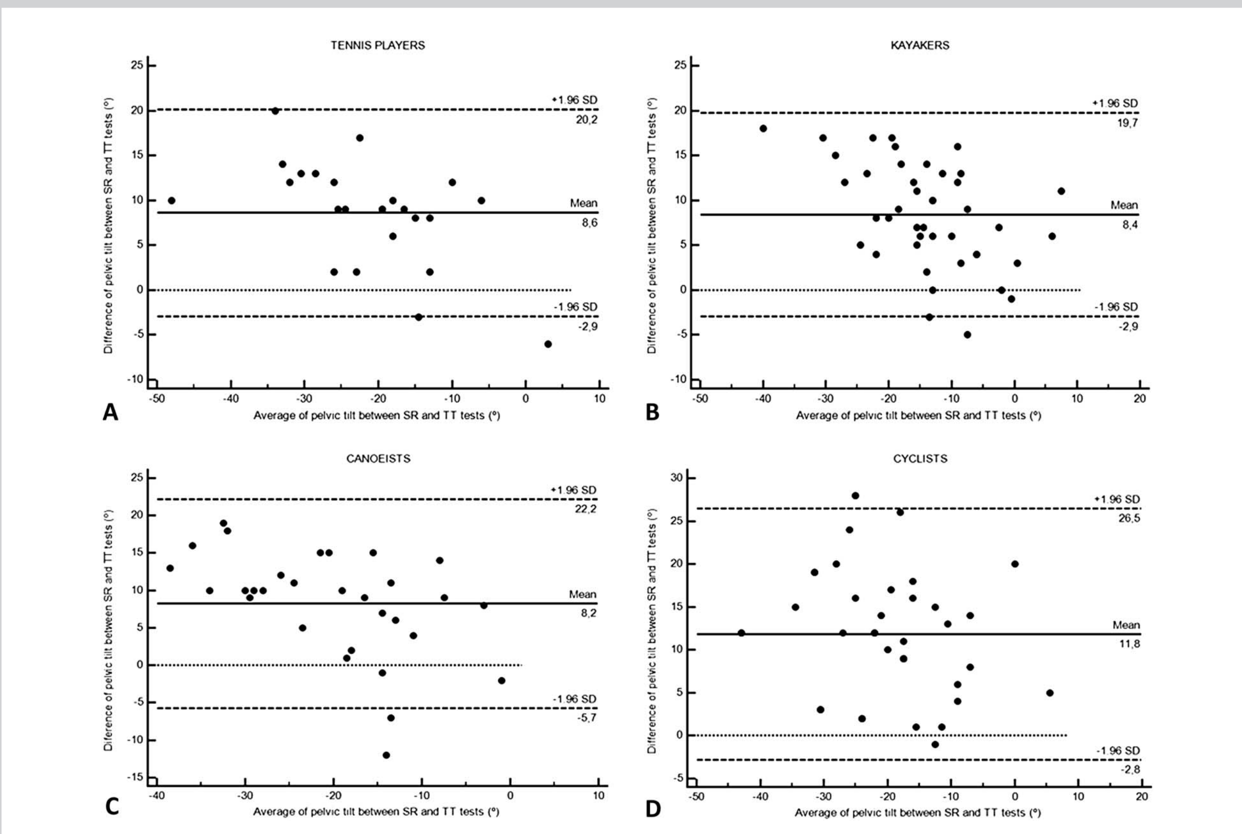

Figure 5. A Bland-Altman plots between pelvic tilt angle in the sit-and-reach and toe-touch tests in tennis players (A), canoeists (B), kayakers (C), and cyclists (D). The bias line and random error lines constituting a 95% limit of agreement are also presented on the plots.

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Table 4. Stepwise multiple regression analysis to identify the hamstring muscle extensibility and spinal parameters (pelvic tilt, lumbar, and thoracic spine—independent variables) influencing the distance achieved in the SR test (dependent variable).*

	Model	Independent variables	Adjusted β coefficients	p	R^2	p
Tennis players ($n = 24$)	1	PSLR	0.78	0.000	0.61	0.000
	2	PSLR	0.51	0.002	0.73	0.000
		Pelvic tilt	0.43	0.006		
		PSLR	0.31	0.003	0.90	0.000
	3	Pelvic tilt	0.63	0.000		
		Lumbar spine	0.44	0.000		
Canoeists ($n = 30$)	1	Pelvic tilt	0.85		0.71	0.000
	2	Pelvic tilt	0.98	0.000	0.86	0.000
		Lumbar spine	0.40	0.000		
		Pelvic tilt	0.99	0.000		
	3	Lumbar spine	0.44	0.000	0.88	0.000
		Thoracic spine	0.17	0.012		
Kayakers ($n = 43$)	1	Pelvic tilt	0.80		0.64	0.000
	2	Pelvic tilt	0.88	0.000	0.73	0.000
		Lumbar spine	0.32	0.000		
Cyclists ($n = 44$)	1	Pelvic tilt	0.90		0.80	0.000
	2	Pelvic tilt	0.88	0.000	0.92	0.000
		Lumbar spine	0.34	0.000		
		Pelvic tilt	0.85	0.000	0.94	0.000
	3	Lumbar spine	0.50	0.000		
		Thoracic spine	0.22	0.001		
		Pelvic tilt	0.74	0.000		
	4	Lumbar spine	0.46	0.000	0.95	0.000
		Thoracic spine	0.22	0.000		
		PSLR	0.16	0.006		

*PSLR = passive straight leg raise test.

Discussion

The main objective of this study was to determine and compare the concurrent validity of the SR and TT tests in different sport disciplines (tennis, kayaking, canoeing, and cycling). Another aim of this study was to evaluate the influence of spinal parameters and/or hamstring muscle flexibility in the SR and TT scores. Multiple regression analyses were used to determine concurrent validity of SR and TT tests as measures of hamstring muscle flexibility. Our results showed that values between PSLR with respect to the SR and TT scores were different depending on the sport discipline. The highest association values were found in tennis players (β = 0.78 and 0.77 for SR and TT tests, respectively) and cyclists (β = 0.76 and 0.74, respectively). In contrast, both canoeists and kayakers showed the lowest values (β ~ 0.67). These values are in concordance with the previous data recorded in the literature (2,24,37) although a high variability exists among studies. Differences in study design, sample characteristics, data analysis, and hamstring criterion measurement protocol may explain the range of described values (23,34). Comparatively, the TT test showed better criterion-related validity than the SR test did in both canoeists and kayakers. In contrast, the cyclists and tennis players reached similar values between both the tests.

Several studies have evaluated the hamstring criterion validity of the SR and TT tests as measures of hamstring flexibility (1–4,17,18,23–25,29,33,36,37). Most studies have analyzed the criterion-related validity of the SR test. Only a few studies also included the TT test. Davis et al. (12) stated that the SR test does not have sufficient concurrent validity to measure hamstring muscle flexibility in young people. They found a correlation coefficient of $r = 0.65$ between the PSLR and SR tests. Castro-Piñero et al. (9) concluded that the criterion-related validity of the SR test for estimating hamstring flexibility is weak in children and adolescents. Hui and Yuen (17) found that the SR test presented a low to moderate validity ($r = 0.46$–0.53). Baltaci et al. (4) found r values in the PSLR and SR tests between 0.53 and 0.63. They considered the SR to be a moderate valid measure of hamstring flexibility. Simoneau (37) reported greater correlation values in sedentary young women ($r = 0.78$). However, all these studies included a nonathlete population. In recent years, some studies have examined the criterion-related validity of the SR and TT tests in athletes. López-Miñarro et al. (24)

found moderate correlation values between PSLR and SR (r= 0.75) and between PSLR and TT (r= 0.69) in young paddlers. Recently, Ayala et al. (1) found a slightly higher correlation between the PSLR and SR tests in futsal players ($\beta = 0.80$). Based on these correlation values, the SR and TT tests have been proposed as validity measures of hamstring muscle flexibility in athletes. In this study, we have evaluated 4 kinds of athletes (tennis players, canoeists, kayakers, and cyclists), and our data have shown that the sport discipline influences the hamstring criterion-related validity of the SR and TT tests. The specific postures and movements of each sport may be an important factor when the validity of the SR and TT tests is studied.

Some variables can influence the score reached in the SR and the TT tests. Anthropometric characteristics and protocol measurement may affect the results (16,18,28,33,35). Furthermore, SR and TT scores may also be affected by spinal characteristics of athletes. Previous studies have shown that specific sport movements and postures adopted by athletes lead to static and dynamic spinal adaptations (22,29–31,40). In this study, different spinal values were detected between athletes. The differences in the correlation values obtained between them may be because of spinal adaptations depending on the sport discipline. Kayakers, canoeists, and cyclists have shown a trend toward thoracic hyperkyphosis in standing and greater lumbar flexion when maximal trunk flexion with knees extended is performed (22,29–31). A similar trend was found in this study. McEvoy et al. (26) reported a significantly higher anterior pelvic tilt in elite cyclists than in sedentary subjects while sitting with knees extended. They justified this difference as a specific adaptation to the prolonged trunk flexion of cyclists on their bicycles. Furthermore, cross-sectional studies have established that people with lower hamstring flexibility show higher thoracic kyphosis and lower lumbar flexion in the lineal tests (14,20,23,30). López-Miñarro and Rodríguez (23) found that hamstring criterion-related validity of the SR and TT tests is influenced by hamstring muscle extensibility in young adults. They found that people with higher hamstring extensibility reached greater correlation values. However, in this study, the kayakers achieved the greatest PSLR angle but they also showed the lowest β value between PSLR and the SR, and the TT tests. This fact could be related to their greater lumbar flexion when maximal trunk flexion with knees extended (20). This has been associated with a prolonged lumbar flexion and posterior pelvic tilt when the paddlers are sitting in their kayak (21).

To identify the factors that influence the SR and TT scores, a stepwise multiple regression analysis was performed. The most common assumption when interpreting SR and TT scores is that subjects with better results have a higher degree of trunk and hip flexibility than those with lower results (4). Our study found that the pelvic tilt and lumbar spine were the most important explanatory variables, significantly and independently associated with the score achieved in SR and TT tests in all groups of athletes. The 31 and 1.6% of the SR score were explained by the PSLR in tennis players and in cyclists, respectively. In canoeists and kayakers, the PSLR did not have a significant influence on the SR score. In a previous study, Chillón et al. (10) found that hip flexibility was the main determinant of the back saver sit-and-reach test score in adolescents, followed by lumbar flexibility. The hip angle independently explained 42% ($p < 0.001$) of the variance in the back saver sit-and-reach test, the lumbar angle explained an additional 30% ($p < 0.001$) of the variance, and the thoracic angle an additional 4% ($p < 0.001$). Recently, Mier and Shapiro (27) concluded that the SR score based in the full reach distance is not an accurate assessment of hamstring flexibility which can be directly measured using the SLR test.

The SLR and knee extension tests are the most recommended measures to determine hamstring muscle flexibility, and they are considered like the gold standard for hamstring flexibility. However, these tests require more equipment, preparation time, and experience than required in lineal tests, which are easier to perform. The main limitation of the SR and TT tests is that score is influenced by several factors. For these reasons, pelvic position has been proposed as an alternative measure of hamstring flexibility (1,11,20). Because hamstring muscles are attached to the ischial tuberosity of the pelvis, their posture should not be affected by spinal curvatures and anthropometric variables (3). Previous studies found AU8 that the pelvic position technique is not a valid method to determine hamstring flexibility (12,19). These studies included a nonathlete population and used a goniometer or an inclinometer for pelvic tilt measurement. Our results showed low to moderate correlation values between the PSLR angle and the pelvic tilt assessed with the Spinal Mouse in both tennis players and canoeists. The kayakers and cyclists showed lower correlation values. In contrast, in all groups of athletes, the SR score showed greater β values with respect to the PSLR than to the pelvic tilt. This finding is in agreement with the Davis et al. (12) findings, which showed greater β values between the SR score and SLR ($\beta = 0.42$) than between pelvic position and the PSLR ($\beta = 0.28$).

In conclusion, this study has shown low to moderate validity in the SR and TT tests as assessing the hamstring flexibility in 4 sport disciplines. Also, it has been reported that a high influence of the pelvic tilt and the lumbar flexion in the distance reached in both SR and TT tests, with little influence of the hamstring extensibility. For these reasons, the SR and the TT tests can be appropriate measures to determine the lumbar spine and pelvic flexibility but not to evaluate hamstring muscle flexibility in tennis players, canoeists, kayakers, and cyclists. The pelvic tilt assessed with a Spinal Mouse cannot be considered an appropriate measure for assessing hamstring muscle flexibility in these athletes. There are other tests, such as the PSLR, which are better to assess the hamstring flexibility.

Practical Applications

This study provides important information to sports coaches about hamstring flexibility evaluation in athletes. The SR and

TT tests are the most common methods of assessing hamstring muscle extensibility in the field setting. Sport discipline appears to be an important variable when these tests are used because some adaptations could be related to specific movements and postures of each sport discipline. For example, the pelvic tilt and lumbar flexion have a greater influence in the score reached in the SR and TT tests than the hamstring flexibility. This study found that the SR and TT scores only demonstrated moderate hamstring criterion-related validity as measures of hamstring flexibility in tennis players and cyclists and low validity in both canoeists and kayakers. For this reason, both SR and TT should be avoided in athletes to determine hamstring muscle flexibility. However, these tests could be used to evaluate the pelvic tilt and lumbar flexion capacity.

Acknowledgments

The authors did not receive any grant for this study. The results of this study do not constitute the endorsement of the product by the authors or the National Strength and Conditioning Association.

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