applied sciences

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Biomechanical Adaptations in Kayakers of Different Competitive Levels and the Relationship with the Kayak Elements

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Received: 23 October 2020; Accepted: 23 November 2020; Published: 25 November 2020

Abstract: A paddler's characteristics can condition the placement of the elements of the boat. The aim of this study was to analyze the differences among kayakers from different skill levels on their sagittal spine position, hamstring extensibility and anthropometric variables; and to determine which variables could be used to determine the arrangement of the elements in the kayak. Thirty-four male sprint kayakers (8 Olympic-level, 13 from the U-23 national team and 13 amateurs) participated in this study. Anthropometric variables, following the protocol of the International Society for the Advancement of Kinanthropometry (ISAK); hamstring extensibility, with active and passive straight leg raise test; sagittal spine position in standing position and in the kayak, and the arrangement of the elements of the boat were measured. The groups with a high skill level showed a lower pelvic tilt in attack position in the kayak than amateurs ($p \leq 0.001$). The U-23 group had a lower hamstring extensibility than amateurs ($p = 0.053$–0.013). The distance from the footrest to the different parts of the seat were dependent on the iliospinale measurement ($R = 0.896$–0.912). In conclusion, there were differences among groups on the sagittal spine position and hamstring extensibility. In addition, the placement of the boat elements was dependent on anthropometric variables, but not on hamstring extensibility or sagittal spine position.

Keywords: anthropometry; canoeing; elite athlete; extensibility; high performance; paddler; proportionality; spinal curvatures

1. Introduction

Canoeing is characterized by the paddler moving through the water on a canoe by the application of a force on the water through the use of an implement, the paddle [1]. Flat water sprint kayaking is one of the disciplines of canoeing. It is a racing sport which uses a double-bladed paddle with the kayaker sitting on the boat [2].

The involvement of the upper limbs predominates in kayaking, although all the propulsive energy must be transferred to the boat through the lower limbs in order to move it through the water [3]. Thus, the main technical difficulty consists in transforming trunk rotation strength in the vertical axis of the paddler into a pushing or propelling force on the sagittal plane through the rapid and powerful extension of the knee on the stroke side, thereby transmitting the force to the boat through the footrest of the kayak [4,5]. Furthermore, an increase in the time spent in the attack phase of the paddling cycle, for applying force for a longer period of time in the water and, as a consequence, to increase performance, is followed by trunk rotation and flexion [1].

This combination of movements is repeated with each stroke during long periods of training. As a consequence of the involvement of the trunk, it has been found that 31% of paddler injuries were located on the lower back [6], even though the upper limb involvement was more pronounced. These injuries usually appear from overuse or accumulation of stress [6] from training and competition.

Based on the theoretical aspects of paddling, it is recommended that paddlers maintain a position that respects a normal spine position [7], and increases the length of the water phase of the stroke through an anteverted pelvic tilt [8]. However, this pelvic tilt depends on hamstring extensibility. Thus, if hamstring shortness is present, the anteversion in a sitting position with legs extended is limited [9]. As a consequence, during trunk flexion, kayakers usually show a pelvic retroversion in the boat, which rectifies the lumbar lordosis and increases thoracic hyperkyphosis. Thoracic hyperkyphosis is characterized by a reduced vertebral joint mobility which must be compensated for by the nearest anatomical structures [10]. Furthermore, trunk flexion changes depend on the speed that the paddler needs [11] as a consequence of needing to increase the length of the water phase of the stroke to maximize velocity, which is achieved through higher trunk flexion. This could be more frequent at elite levels, but there are no previous studies that have analyzed this.

There are three factors that can condition the pelvic tilt and the sagittal spine position in the boat during the action of paddling. The first is the distance between the seat and the footrest of the boat. This distance should allow trunk rotation [3] and the transmission of force to the boat [12]. The other two are the hamstring extensibility of the paddler and the anthropometric proportionality. In fact, some theories state that hamstring extensibility and anthropometric variables influence the placement of the different internal elements of the boat [13,14]. However, no previous study has investigated this relationship.

Consequently, this study was undertaken to analyze the differences on spine position, hamstring extensibility and anthropometric variables between kayakers from different competition levels and to determine which variables could determine the placement of the elements in the boat. It was hypothesized that differences on spine position on the boat, hamstring extensibility and anthropometric variables would be found between the different competition levels because of natural selection or a physical adaptation in high-level kayakers, and that the placement of the elements in the boat depends on lengths because other factors can be changed with training.

2. Materials and Methods

2.1. Participants

Sample size and power were established in connection with a standard deviation for trochanterion–tibiale laterale length from male Olympic paddlers [15]. The sample size for this study consisted of 34 participants, providing a power of 95% and a significance level of = 0.05; an estimated error of 0.84 cm is reported. Rstudio 3.15.0 software was used to establish the sample size.

Thirty-four male sprint kayakers (age: 21.50 ± 3.91 years old, previous training experience: 10.97 ± 3.88 years; weekly training sessions: 7.82 ± 2.21 sessions/week) participated in this study. The inclusion criteria were: (1) had a minimum experience of 6 years in kayaking; (2) were active at a competitive level at the time of the experiment; (3) had not suffered an sports injury in the previous four months; (4) had not had an operation on spine or hamstring musculature; and (5) had not been diagnosed with any spinal disorder. The kayakers were divided into three groups: one with Olympics kayakers from the elite kayak group of the Spanish national team (Olympic group); the second with kayakers from the Spanish national team Under-23 (U-23 group); and a third with recreational kayakers from different clubs (amateur group).

All the participants were informed about the purpose of the present investigation and provided their informed consent prior to participating on the study. The study was approved by the institutional ethics committee (Code: CE031912) and the design was done following the Declaration of Helsinki.

2.2. Measures

2.2.1. Anthropometry

The following were measured: two basic measurements, body mass and height; and four lengths and heights, trochanterion-tibiale laterale, foot, iliospinale, and tibiale laterale. The measurements were taken by an accredited anthropometrist, following the instructions from the International Society for the Advancement of Kinanthropometry (ISAK) [16]. The measurements were taken two or three times if the difference between the first two measurements was higher than 1%. The final value was the mean or the median, respectively. The intra-evaluator technical error of measurement (TEM) for the present study was 0.21%, while the inter-evaluator TEM with respect to an ISAK criterion was 0.48%. A Seca 862 scale (Seca, Hambourg, Germany) was used to measure body mass. A portable stadiometer (Cescorf Ltd., Porto Alegre, Brazil) was used to measure height. A Pro model segmometer (Cescorf Ltd., Porto Alegre, Brazil), and a large sliding caliper (Cescorf Ltd., Porto Alegre, Brazil) were used to measure lengths.

2.2.2. Sagittal Spinal Curvatures and Pelvic Tilt

The sagittal spine and pelvic tilt were evaluated using the Spinal Mouse system (Idiag, Fehraltdorf, Switzerland) [17]. The measurements were taken in relaxed standing position, relaxed seating in the boat (base position), and in the maximum entry position in the kayak on both sides (attack position). For the assessment of the standing position, the subject assumed a relaxed position, with the head looking forward, arms hanging on the sides, knees extended normally and the feet shoulder width apart. In the kayak positions, the participants were measured with their own kayak and paddle in base position and attack position (right and left entry). In the base position, the paddlers were seated in the kayak with the paddle resting on their thighs and their knees slightly flexed [18]. In the maximum right entry position, the kayakers adopted the position at which the right blade contacts the furthest point at the junction between the hull and the deck; while in maximum left entry position the kayakers adopted the position at which the left blade contacts the furthest point at the junction between the hull and the deck. In the attack positions, the hands had to be completely closed on the paddle pole as a control of the real grip of the paddle and to promote the involvement of the trunk.

2.2.3. Hamstring Extensibility

Hamstring extensibility was measured through an active (ASLR) and passive straight leg raise (PSLR) test on each limb in a random order. While the participant was in the supine position with the lower extremities at a 0° hip flexion, a Uni-Level Acumar digital inclinometer model ACU 360 (Lafayette Instrument Co., Lafayette, IN, USA) was placed over the distal tibia. A lumbar protection support (Lumbosant; Orthopaedic, Murcia, Spain) was used to maintain a neutral lumbar lordosis during the test. The ankle of the tested leg was restrained in plantar flexion to avoid adverse neutral tension. Moreover, the pelvis was fixed to avoid posterior pelvic tilt and an auxiliary tester maintained the contralateral leg straight to avoid external rotation. In the ASLR test, the kayakers actively lifted their own leg into a hip flexion position. In the PSLR, the kayaker's leg was passively lifted by the tester into hip flexion. The knee remained straight during the leg raise test. The criterion score of hamstring extensibility was the maximum angle read from the digital inclinometer at the end point for each leg. The end point for the straight leg raise was determined by one or both criteria: (a) the participants reported pain in hamstring muscle and/or (b) palpable onset of pelvic rotation. No prior warming up was performed due to its influence on the hamstring extensibility test results [19]. Only one repetition per test was performed as in previous studies [17,20].

2.2.4. Kayak Measurements

The following distances were measured in all the participant's kayaks: the distance from the front edge of the seat to the center of the footrest, defined as the horizontal midpoint of the lower edge of the groove through which the tiller is inserted (A); from the front edge of the seat to the depression of the seat (B); and from the front edge of the seat to the useful end of the seat, being defined as the back part of the seat with which the paddler could have contact during practice (C) (Figure 1). The measurements were taken with a Pro model segmometer (Cescorf Ltd., Porto Alegre, Brazil).

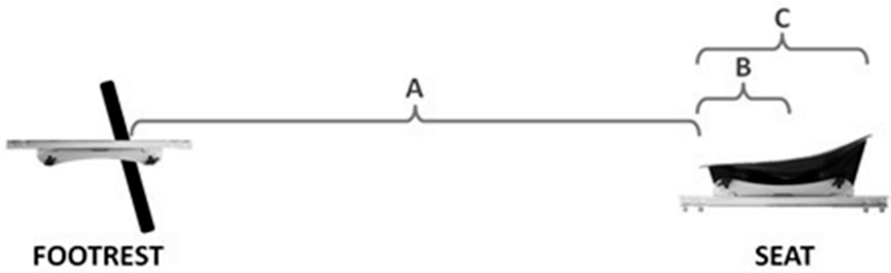

Figure 1. Measurements of the equipment.

2.3. Design and Procedures

All the participants were assessed for their anthropometric variables, hamstring extensibility and sagittal spine position by the same researcher. Prior to this, the participants were asked not to do physical exercise on the day of the assessment or vigorous physical exercise on the previous 48 h. In the tests where the boat and the paddle were necessary, each paddler used his own equipment. The distances between the different elements of the boat of each kayaker were also measured. The tests were performed in a random order, leaving 3 min of rest between tests. All the measurements were taken in the same room, with a standardized temperature of 25 °C.

2.4. Statistical Analysis

The statistical analysis was performed with the IBM SPSS software, version 20 (IBM, Endicott, NY, USA). The normality and homogeneity of the variance was analyzed via the Shapiro–Wilks and Levene's tests, respectively. The variables followed a normal distribution. Parametric tests were utilized for the analysis. To describe the sample, the mean value and the standard deviation of each variable were obtained. A one-way analysis of variance (ANOVA) was performed to analyze the intergroup differences in the different variables. The level of significance for all tests was set a priori at $p < 0.05$. For those variables that showed significant differences, a pairwise comparison with the Bonferroni correction was performed, with the significance criterion adjusted to $p < 0.016$. The confidence interval (CI) of the differences (95% CI) was included. The partial eta-squared (η2p) for variance analysis was used to calculate the effect size (ES), and this was defined as small: ES ≥ 0.10; moderate: ES ≥ 0.30, large: ES ≥ 1.2; or very large: ES ≥ 2.0, with an error of $p \leq 0.05$ utilized [21]. Pearson's correlation coefficient was used to determine the correlation values between sagittal spine position, hamstring extensibility and anthropometric variables with respect to the position of the elements in the boat and between pelvic tilt and SLR. A multiple linear regression analysis through successive steps was carried out with the variables that showed significance.

3. Results

Significant differences were found in body mass and trochanterion-tibiale laterale length, in PSLR and ASLR tests, and in pelvic tilt in attack position in the kayak between the three groups, with a low to moderate size effect. There were no significant differences in the other variables (Tables 1 and 2).

Table 1. Anthropometric characteristics, hamstring extensibility, and sagittal spinal curvatures of the different groups of kayakers (mean ± standard deviation).

Variable	Olympics (n = 8)	U-23 (n = 13)	Amateur (n = 13)	F and *p* Value
Age (years-old)	25.7 ± 3.8	18.8 ± 1.5	21.6 ± 3.4	F = 14.032; $p < 0.001$
Body Mass (kg)	87.1 ± 7.4	76.8 ± 6.9	74.2 ± 6.8	F = 8.808; $p = 0.001$
Height (cm)	184.8 ± 4.55	179.1 ± 5.2	180.4 ± 7.2	F = 2.369; $p = 0.119$
Iliospinale H (cm)	102.7 ± 2.7	98.5 ± 3.3	100.2 ± 5.6	F = 2.320; $p = 0.114$
Trochanterion—tibiale laterale L (cm)	48.7 ± 2.0	45.4 ± 2.7	46.1 ± 3.0	F = 3.932; $p = 0.035$
Tibiale laterale H (cm)	48.3 ± 1.3	46.4 ± 2.3	47.4 ± 2.60	F = 1.992; $p = 0.154$
Foot L (cm)	28.2 ± 1.4	27.00 ± 1.0	27.0 ± 1.2	F = 3.267; $p = 0.052$
SLR Right Passive (°)	91.5 ± 11.1	85.6 ± 9.3	94.6 ± 7.6	F = 3.223; $p = 0.053$
SLR Left Passive (°)	90.4 ± 11.7	82.8 ± 8.7	94.2 ± 8.5	F = 4.915; $p = 0.014$
SLR Right Active (°)	71.0 ± 13.4	72.3 ± 8.6	82.1 ± 6.6	F = 4.979; $p = 0.013$
SLR Left Active (°)	72.6 ± 12.9	71.1 ± 7.0	80.6 ± 8.5	F = 3.868; $p = 0.032$
Thoracic curv. Stand (°)	53.1 ± 9.3	50.5 ± 3.6	47.6 ± 9.6	F = 1.302; $p = 0.287$
Lumbar curv. Stand (°)	−24.4 ± 7.5	−22.8 ± 7.2	−26.5 ± 4.8	F = 1.070; $p = 0.355$
Pelvic tilt Stand (°)	9.7 ± 4.1	10.9 ± 5.8	14.5 ± 4.4	F = 2.77; $p = 0.078$
Thoracic curv. BP (°)	33.4 ± 9.7	36.0 ± 8.2	34.5 ± 9.4	F = 0.219; $p = 0.804$
Lumbar curv. BP (°)	20.0 ± 6.5	20.6 ± 7.7	16.1 ± 7.2	F = 1.432; $p = 0.254$
Pelvic tilt BP (°)	−8.0 ± 4.8	−9.4 ± 6.4	−6.1 ± 5.9	F = 0.976; $p = 0.388$
Thoracic curv. AP Right (°)	33.9 ± 10.2	37.7 ± 7.7	32.8 ± 11.4	F = 0.844; $p = 0.448$
Lumbar curv. AP Right (°)	23.9 ± 7.0	29.0 ± 6.6	26.5 ± 7.2	F = 1.377; $p = 0.267$
Pelvic tilt AP Right (°)	−1.7 ± 4.0	0.3 ± 6.5	10.8 ± 7.4	F = 12.799; $p < 0.001$
Thoracic curv. AP Left (°)	34.7 ± 9.6	34.3 ± 8.1	29.8 ± 12.3	F = 0.857; $p = 0.434$
Lumbar curv. AP Left (°)	22.5 ± 9.5	32.2 ± 7.3	27.9 ± 5.7	F = 4.392; $p = 0.021$
Pelvic tilt AP Left (°)	−2.6 ± 6.1	0.7 ± 5.4	11.5 ± 6.4	F = 16.997; $p < 0.001$

L: Length; H: Height; SLR: Straight Leg Raise test; curv: curvature; Stand: Standing; BP: Base position; AP Right: Attack position from the right; AP Left: Attack position from the left.

Table 2. Inter-group differences.

	Variable	Mean Difference	95% CI	*p* Value	Effect Size
Olympic-U-23	Age (years-old)	7.0	3.03; 10.93	<0.001	0.654
	Body Mass (kg)	10.3	0.89; 19.68	0.008	0.353
	Height (cm)	5.7	−2.28; 13.66	0.122	0.255
	Iliospinale H (cm)	4.1	−1.60; 9.80	0.117	0.315
	Trochanterion—tibiale laterale L (cm)	3.3	−0.30; 6.90	0.03	0.318
	Tibiale laterale H (cm)	2.0	−1.04; 5.00	0.176	0.206
	Foot L (cm)	1.2	−0.37; 2.86	0.084	0.223
	SLR Right Passive (°)	5.9	−6.42; 18.19	0.485	0.083
	SLR Left Passive (°)	7.5	−5.09; 20.15	0.251	0.131
	SLR Right Active (°)	−1.3	−13.79; 11.17	1	0.004
	SLR Left Active (°)	1.5	−10.84; 13.94	1	0.007
	Thoracic curv. Stand (°)	2.6	−7.83; 13.00	1	0.042
	Lumbar curv. Stand (°)	−1.5	−10.22; 7.16	1	0.011
	Pelvic tilt Stand (°)	−1.2	−7.80; 5.46	1	0.013
	Thoracic curv. BP (°)	−2.6	−14.79; 9.54	1	0.023
	Lumbar curv. BP (°)	−0.6	−10.38; 9.15	1	0.002
	Pelvic tilt BP (°)	1.4	−6.57; 9.34	1	0.014
	Thoracic curv. AP Right (°)	−3.8	−17.12; 9.48	1	0.047
	Lumbar curv. AP Right (°)	−5.1	−14.45; 4.20	0.330	0.132
	Pelvic tilt AP Right (°)	−2.1	−10.68; 6.57	1	0.033
	Thoracic curv. AP Left (°)	0.4	−13.32; 14.20	1	0.001
	Lumbar curv. AP Left (°)	−9.7	−19.60; 0.14	0.018	0.269
	Pelvic tilt AP Left (°)	−3.3	−11.37; 4.74	0.680	0.081
	Age (years-old)	4.1	0.18; 8.09	0.011	0.26
	Body Mass (kg)	12.8	3.42; 22.20	0.001	0.466
	Height (cm)	4.4	−3.59; 12.35	0.33	0.111
	Iliospinale H (cm)	2.4	−3.27; 8.13	0.635	0.064
	Trochanterion - tibiale laterale L (cm)	2.6	−1.01; 6.19	0.117	0.197
	Tibiale laterale H (cm)	0.9	−2.07; 3.96	1	0.045

Table 2. *Cont.*

	Variable	Mean Difference	95% CI	*p* Value	Effect Size
Olympic-Amateur	Foot L (cm)	1.2	−0.38; 2.86	0.086	0.192
	SLR Right Passive (°)	−3.1	−15.42; 9.19	1	0.03
	SLR Left Passive (°)	−3.9	−16.47; 8.76	1	0.039
	SLR Right Active (°)	−11.1	−23.55; 1.40	0.037	0.255
	SLR Left Active (°)	−8.0	−20.38; 4.40	0.187	0.135
	Thoracic curv. Stand (°)	5.5	−4.91; 15.93	0.369	0.081
	Lumbar curv. Stand (°)	2.2	−6.53; 10.86	1	0.034
	Pelvic tilt Stand (°)	−4.7	−11.34; 1.92	0.124	0.241
	Thoracic curv. BP (°)	−1.2	−13.33; 11.00	1	0.004
	Lumbar curv. BP (°)	3.9	−5.84; 13.69	0.713	0.076
	Pelvic tilt BP (°)	−1.8	−9.80; 6.11	1	0.028
	Thoracic curv. AP Right (°)	1.0	−12.27; 14.33	1	0.002
	Lumbar curv. AP Right (°)	−2.7	−11.99; 6.67	1	0.035
	Pelvic tilt AP Right (°)	−12.6	−21.22; −3.97	<0.001	0.505
	Thoracic curv. AP Left (°)	5.0	−8.78; 18.74	0.859	0.048
	Lumbar curv. AP Left (°)	−5.427	−15.29; 4.45	0.329	0.125
	Pelvic tilt AP Left (°)	−14.1	−22.14; −6.03	<0.001	0.565
U−23-Amateur	Age (years-old)	−2.8	−6.29; 0.60	0.057	0.241
	Body Mass (kg)	2.5	−5.68; 10.72	1	0.035
	Height (cm)	−1.3	−8.26; 5.65	1	0.012
	Iliospinale H (cm)	−1.7	−6.65; 3.30	0.961	0.035
	Trochanterion - tibiale laterale L (cm)	−0.7	−3.85; 2.43	1	0.017
	Tibiale laterale H (cm)	−1.0	−3.67; 1.60	0.745	0.046
	Foot L (cm)	−0.0	−1.42; 1.41	1	0.000
	SLR Right Passive (°)	−9.0	−19.74; 1.74	0.052	0.234
	SLR Left Passive (°)	−11.4	−22.40; −0.37	0.012	0.323
	SLR Right Active (°)	−9.8	−20.66; 1.12	0.034	0.305
	SLR Left Active (°)	−9.5	−20.35; 1.28	0.038	0.288
	Thoracic curv. Stand (°)	2.9	−6.17; 12.01	1	0.042
	Lumbar curv. Stand (°)	3.7	−4.00; 11.28	0.465	0.089
	Pelvic tilt Stand (°)	−3.54	−9.33; 2.24	0.23	0.113
	Thoracic curv. BP (°)	1.5	−9.16; 12.08	1	0.007
	Lumbar curv. BP (°)	4.5	−3.98; 13.06	0.362	0.091
	Pelvic tilt BP (°)	−3.2	−10.18; 3.72	0.52	0.068
	Thoracic curv. AP Right (°)	4.8	−6.76; 16.45	0.661	0.063
	Lumbar curv. AP Right (°)	2.5	−5.68; 10.61	1	0.033
	Pelvic tilt AP Right (°)	−10.5	−18.07; −3.01	0.001	0.384
	Thoracic curv. AP Left (°)	4.5	−7.47; 16.55	0.798	0.049
	Lumbar curv. AP Left (°)	4.3	−4.31; 12.92	0.432	0.104
	Pelvic tilt AP Left (°)	−10.8	−17.80; −3.74	<0.001	0.47

L: Length; H: Height; SLR: Straight Leg Raise test; curv: curvature; Stand: Standing; BP: Base position; AP Right: Attack position from the right; AP Left: Attack position from the left.

A positive correlation was found between ASLR with both legs and pelvic tilt in standing position (r = 0.35, $p = 0.04$; and r = 0.42, $p = 0.01$ in right and left legs, respectively), and attack position for the right (r = 0.58, $p < 0.001$; and r = 0.47, $p = 0.005$ in right and left legs, respectively) and left (r = 0.55, $p = 0.001$; and r = 0.44, $p = 0.009$ in right and left legs, respectively). No differences were found in the base position on the kayak ($p > 0.05$).

The correlation analysis showed a significant correlation between the anthropometric variables and the position of the elements in the boat (Table 3). There was no correlation between the kayak measurements, the sagittal spine position and the hamstring extensibility.

The regression analysis showed that the iliospinale measure predicted the placement of the elements in the boat (Table 4).

Table 3. Correlations between the placement of the material and the anthropometric variables.

Variable	Footrest-Seat Edge	Footrest-Seat Depression	Footrest-Seat End
Height (cm)	r = 0.86; $p \leq 0.001$	r = 0.86; $p < 0.001$	r = 0.85; $p < 0.001$
Body mass (kg)	r = 0.59; $p \leq 0.001$	r = 0.61; $p < 0.001$	r = 0.57; $p < 0.001$
Iliospinale H (cm)	r = 0.90; $p \leq 0.001$	r = 0.90; $p < 0.001$	r = 0.91; $p < 0.001$
Trochanterion—tibiale laterale L (cm)	r = 0.80; $p \leq 0.001$	r = 0.82; $p < 0.001$	r = 0.81; $p < 0.001$
Tibiale laterale H (cm)	r = 0.77; $p \leq 0.001$	r = 0.75; $p < 0.001$	r = 0.78; $p < 0.001$
Foot L (cm)	r = 0.64; $p \leq 0.001$	r = 0.64; $p < 0.001$	r = 0.65; $p < 0.001$
SLR Right Passive (°)	r = −0.11; $p = 0.949$	r = 0.01; $p = 0.931$	r = 0.12; $p = 0.508$
SLR Left Passive (°)	r = −0.02; $p = 0.890$	r = −0.01; $p = 0.962$	r = 0.12; $p = 0.491$
SLR Right Active (°)	r = −0.04; $p = 0.819$	r = 0.01; $p = 0.964$	r = 0.07; $p = 0.701$
SLR Left Active (°)	r = −0.20; $p = 0.253$	r = −0.16; $p = 0.931$	r = 0.12; $p = 0.508$
Thoracic curv. Stand (°)	r = 0.34; $p = 0.046$	r = 0.37; $p = 0.030$	r = 0.26; $p = 0.141$
Lumbar curv. Stand (°)	r = −0.09; $p = 0.623$	r = −0.09; $p = 0.591$	r = −0.10; $p = 0.556$
Pelvic tilt Stand (°)	r = −0.05; $p = 0.785$	r = −0.06; $p = 0.717$	r = −0.03; $p = 0.854$
Thoracic curv. BP (°)	r = 0.11; $p = 0.516$	r = 0.12; $p = 0.507$	r = 0.02; $p = 0.507$
Lumbar curv. BP (°)	r = −0.18; $p = 0.318$	r = −0.14; $p = 0.413$	r = −0.15; $p = 0.410$
Pelvic tilt BP (°)	r = 0.18; $p = 0.296$	r = 0.14; $p = 0.442$	r = 0.18; $p = 0.318$
Thoracic curv. AP Right (°)	r = 0.07; $p = 0.694$	r = 0.07; $p = 0.691$	r = −0.01; $p = 0.949$
Lumbar curv. AP Right (°)	r = 0.36; $p = 0.036$	r = 0.39; $p = 0.022$	r = 0.29; $p = 0.099$
Pelvic tilt AP Right (°)	r = −0.16; $p = 0.377$	r = −0.15; $p = 0.394$	r = −0.11; $p = 0.552$
Thoracic curv. AP Left (°)	r = 0.01; $p = 0.951$	r = 0.03; $p = 0.856$	r = −0.10; $p = 0.573$
Lumbar curv. AP Left (°)	r = 0.08; $p = 0.661$	r = 0.11; $p = 0.525$	r = 0.05; $p = 0.798$
Pelvic tilt AP Left (°)	r = −0.19; $p = 0.269$	r = −0.18; $p = 0.318$	r = −0.16; $p = 0.374$

L: Length; H: Height; SLR: Straight Leg Raise test; Curv: Curvature; Stand: Standing; BP: Base position; AP Right: Attack position from the right; AP Left: Attack position from the left.

Table 4. Predictive formulas of the distance between the different internal equipment of the kayak.

Predictive Formulas	R	R^2	95% CI	SE	F	*p*
Distance Footrest–Seat edge = −11.939 + 0.87 · IL	0.896	0.804	0.715; 1.025	0.076	130.943	$p < 0.001$
Distance Footrest –Seat depression = 4.878 + 0.87 · IL	0.900	0.811	0.719; 1.022	0.074	136.926	$p < 0.001$
Distance Footrest–Seat end = 10.79 + 0.885 · IL	0.912	0.831	0.741; 1.028	0.070	157.739	$p < 0.001$

IL: Iliospinale height; SE: Standard error.

4. Discussion

The aim of the research was to analyze the sagittal spine position, hamstring extensibility and anthropometric variables of kayakers at different skill levels. As hypothesized, an important finding of the present study was that the amateur group showed significantly higher hamstring extensibility than the other groups. This could be due to the shortening of the hamstring musculature caused by the continuous stretching-shortening cycles of this musculature during paddling [9,11], which are more numerous for the higher skilled paddlers, as they train longer per session, and have more sessions per week with a higher intensity with respect to the cycle frequency [22].

Another important finding was that no differences were found in the sagittal spine position in standing and base positions in the kayak between groups. Similar results have been found in the standing position when comparing kayakers with athletes of different sports [17], and with respect to junior kayakers in relaxed seating in the boat [23]. This could be due to the absence or lack of muscle tension in non-maximum positions.

The results of this study show that there were significant differences in the pelvic tilt in the attack positions between the Olympic group and the amateur group. The amateur group had a position of pelvic anteversion, the U-23 group showed a position near neutral, and the Olympic group had a pelvic retroversion. No previous studies have been found that analyzed kayakers in this position on the boat, but findings have been found from kayakers in maximum trunk flexion with extended knees positions, which have shown that sagittal spine position and pelvic tilt were influenced by hamstring extensibility in these positions [20,24]. Thus, it is possible that the amateur group, due to their higher hamstring extensibility, could maintain the pelvis in the anteversion position during maximum attack positions [18], which allows for a normal position of thoracic and lumbar curvatures. However, higher-skill level groups showed changes in normal pelvic tilt and spine curvatures as a consequence of the lower hamstring extensibility. Nevertheless, hamstring extensibility can also be influenced by paddler position on the boat, especially in paddlers with a high volume of training [25]. Further research should be undertaken to investigate the interdependence of these variables with a longitudinal design.

Some reports have analyzed the anthropometric profile of kayakers, but only a few of them have included the lengths of the lower limbs [1,7,15,26,27]. A possible explanation for this may be due to the different aims of the research studies or the lack of a comprehensive view about the influence of the lower limbs on sport performance.

A longer thigh could provide a competitive advantage when generating force through the system of levers created during paddling [28]. The present study found that the U-23 group had a trochanterion-tibiale length (thigh length) that was significantly shorter than the Olympic group. A possible explanation for this could be that the kayakers from the U-23 group were in the final part of their growing stage, which occurs in the cephalocaudal direction [29], so the femurs could still be growing longitudinally. Along this line, previous studies with young paddlers have found shorter thigh lengths than in the present study [30]. Not surprisingly, in another study with high-performance adult paddlers, similar values were found for the thigh length as reported for the current paddlers [28].

Another important finding was that kayakers from the Olympic group showed significantly higher values in body mass than the rest of the groups, followed by the U-23 group. Previous studies have found that body mass was highly correlated with performance in rowers [31]. Nevertheless, previous studies have shown that muscle mass in kayakers is higher in higher competitive levels than in lower levels [32,33]. Body mass is a variable that cannot differentiate between fat and muscle mass, and muscle mass has a higher density than fat mass, making it heavier [34], which could justify the differences in body mass between groups.

No significant differences were found in height, iliospinale, and tibiale laterale measurements and foot length, although the U-23 group showed the lowest values, followed by the recreational group, with higher values shown by the Olympic group. This may be explained by the fact that the U-23 group was in their final period of growing, while the others had already completed it [35], although similar heights to the current paddlers have been found in young world-class elite kayakers [32]. Olympic-level kayakers and medalists in world championships were taller than the current sample, although the world-class elite group was closest to the kayakers of the present study [33]. Lastly, the university-level kayakers were shorter than the kayakers of the present study [36]. These results are supported by Sitkowski (2002) who noted that high-performance kayakers were taller than low-performance paddlers. Although a similar trend was found in the present study, significant differences were not found in our sample. Furthermore, it is possible that the competition distance has an influence on this factor, as kayakers who compete in shorter competition distances are usually taller than those who compete in longer distance competitions [37]. Therefore, future research on this matter is necessary.

As for the question about whether the placement of elements in the boat was dependent on anthropometric variables, sagittal spine position, or hamstring extensibility, the main finding was that the variable with the highest relationship was the iliospinale measurement, with an R^2 score of 0.8. This could be due to the fact that the kayaker, who depends on lower limb length, needs to place the seat at a specific distance. This is necessary for flexing the knees in an angle from 110–120 to 147–162 [2,38] without limiting trunk rotation during the paddling motion to allow for an optimal production of muscle strength, length and type of stroke, and transmission of forces to the boat [13]. This finding is contrary to a previous study, which suggested that the placement of the elements in the boat was dependent on height ($R^2 = 0.589$) [13]. This discrepancy could be attributed to the study by Ong et al. [13], which did not include lower limb lengths as independent variables. It can thus be suggested that the iliospinale measurement could be the best predictor of the dependence of the boat elements, based on the R^2 scores. Future studies on the current topic are therefore recommended.

The main practical application from the present study is the recommended use of the iliospinale measurement as a predictor of the distance between the elements in the boat. The use of these distances (and their change) could be essential during the periods of growth and maturation due to the changes in a paddler's anthropometric variables, and it could also be easily implemented, as the placement of the elements in the boat is customizable. Thus, the quantification and ongoing evaluation of these variables during the period of growth is essential. Furthermore, when kayakers begin to practice, they do not know what kind of guidelines should be used to correctly place the different kayak elements, as kayakers presently set the elements based on feeling, and their non-effective placement could decrease the effectiveness of the stroke and increase the risk of injury. Another practical application could be that an adequate active hamstring extensibility may be necessary to allow the free movement of the pelvis during the attack position. As a consequence, it may be necessary to include active stretching for kayakers, with an appropriate volume that has to be established based on the volume of training on the boat.

A limitation of the study was the impossibility of taking the measurements dynamically during the stroke and the analysis of the spine with a 3D model. In addition, the sample analyzed was small in size. This is due to the sample universe on including the Spanish national Olympic team and the U-23 team.

5. Conclusions

There were differences among groups on the sagittal spine position and hamstring extensibility. In addition, the placement of the boat elements were dependent on the anthropometric variables, but not on the hamstring extensibility or the sagittal spine position.

Author Contributions: Conceptualization, T.A.-L., R.V.-C.; methodology, T.A.-L. and R.V.-C.; formal analysis, T.A.-L. and R.V.-C.; investigation, T.A.-L., R.V.-C., F.E.-R. and P.J.M.-P.; resources, F.E.-R. and P.J.M.-P.; data curation, T.A.-L.; writing—original draft preparation, T.A.-L., R.V.-C., F.E.-R. and P.J.M.-P.; writing—review and editing, T.A.-L., R.V.-C., F.E.-R. and P.J.M.-P.; supervision, F.E.-R. and P.J.M.-P.; project administration, F.E.-R. and P.J.M.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to acknowledge the participation of the paddlers and the collaboration by coaches to carry out this project.

Conflicts of Interest: The authors declare no conflict of interest.

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