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Relationship between Kayaking Movement on Water and Physical Flexibility Among High-School Canoe Sprint Athletes [Version 1, 2 Approved with Reservations]

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Abstract

The purpose of this study was to verify the relationship between kayak movements on the water and physical flexibility in the kayakers. Subjects were 24 male kayakers and as physical flexibility data, movable range of trunk rotation, hip joint internal and external rotation, finger floor distance (FFD), heel buttock distance (HBD) and straight leg raise (SLR) were evaluated. The motion was filmed during kayaking on the flat-water using two digital video cameras. Reflective landmarks were pasted on all subjects and the boat. From each image, catching phase and middle phase were caught and the angles of trunk, shoulder and elbow joints were measured. The correlation of physical flexibility data and movement analyzing data were analyzed. In the catch phase, there was moderate-strong positive correlation between the trunk rotation (flexibility) and the shoulder horizontal flexion angle, moderate-strong negative correlation between the hip internal rotation (flexibility) and the shoulder horizontal flexion angle, and a strong negative correlation between SLR and the shoulder flexion angle. In the middle phase, there was moderate negative correlation between SLR and the trunk rotation angle, and moderate negative correlation between SLR and the trunk flexion angle was also observed.

Keywords
Movement analysis; Hip joint flexibility; Kayak; Canoe sprint; Trunk rotation; Novice kayakers; Prevention of disorders

Introduction

Canoeing and kayaking are upper-body sports that have varying demands on the body, depending on the type of contest and distance covered [1]. Canoe sprint is a competition in which competitors race a particular distance (200 m, 500 m, or 1000 m) in static water in a boat with one, two, or four seats. There are two types of canoe boats: the kayak and Canadian canoe. The kayak is covered with a deck; the paddler is seated in the cockpit on the deck and uses a paddle with two blades at both ends. In the Canadian canoe, the paddler is in a kneeling position and uses a paddle with a blade at only one end. It requires a trunk rotation movement for paddling while maintaining balance on the unstable ship, in addition to the ability to advance the boat by transferring the power of the whole body instantaneously to the paddle. When limited to kayakers, even though kayak movement is a full-body exercise, paddlers can easily tend to use limited part of the body while they maintain the sitting position for a long time and experience repeated load on the same part, resulting in specific disorders such as low back pain and shoulder pain. It has been reported that canoe sprint athletes tend to have non-traumatic injuries, particularly because of overload of the anatomical structures of the trunk and shoulders [2,3].

Many reports featuring kayaking have been reported from various viewpoints such as performance improvement [4], body composition and physical fitness [5], and physiological ability [6,7]. There are some reports on the biomechanics of kayaking movement [8-11]; however, most of these reports are on the relationship between biomechanics and performance and few are on disorder prevention. In addition, an ergometer has been used to analyze kayaking movement in these studies; this is a very useful tool for scientific analysis because of the difficulty in measuring movement on water and its efficacy has been verified [12]. However, there are no reports on the actual kayaking movement on water, which is thought to be very important for clarifying how movements or physical stress are forced to kayakers.

The aim of this study was to verify the relationship between kayaking movement on water and physical flexibility among kayakers.

Methods

Subjects

We evaluated 24 male kayakers (age 17.4 ± 0.8 years, height 175.4 ± 8.2 cm, weight 68.1 ± 6.4 kg). None of the subjects had any injuries or functional disorders. All of them had at least 1 year of experience as a kayaker (average career duration 2.2 ± 0.5 years). All the subjects and their parents were informed regarding the purpose and procedure of the study, and they provided written informed consent before participation. This study was approved by the Gunma University Hospital Clinical Research Ethics Committees (No. 12-37).

Physical Flexibility Data

To obtain the movable range of trunk rotation, the angle formed by the line connecting both the posterior superior iliac spines and the line connecting both the acromia was measured. To obtain data on the movable range of hip joint rotation, the angle formed by the vertical line from the patella and the center line of the lower thigh was measured in a supine position with hip joint flexed at 90°; both internal rotation and external rotation were measured. To obtain data on muscle tightness, three parameters were measured: finger floor distance (FFD), heel buttock distance (HBD), and straight leg raise (SLR). FFD, which is defined as the parameter showing the tightness of hamstrings and back muscles, was measured by the distance between the fingertip and floor in a standing position with the knees extended and trunk maximally bent. HBD was measured by the knee flexion angle in a prone position, and SLR was measured by the hip flexion angle with the knee extended in a supine position.

Angle Data from the Kayaking Movement

The kayaking movement was captured was as follows: the filming point was the space between two ropes hanging down from a bridge; each subject passed through the space while paddling at full effort. The distance between the two ropes was 9 m, and the paddling up distance was approximately 50 m. The setup is shown in Figure 1. The kayaking movement was captured during paddling on still water using two digital video cameras (HDR-XR550V, SONY); frame rate was set 30fps and shutter speed was set 1/60 s. One camera was set at 23.7 m from the filming point at a fixed height of 1 m, and it captured the movement in the sagittal plane. The other camera was fixed to the bridge, which was 7.7 m above the filming point, and it captured the movement in the horizontal plane. The installation position of the cameras is shown in Figure 2. Both the cameras were adjusted to catch the full range of the subjects and boats during two and three times paddling, and they were synchronized by a dropping a stone into water. Reflective markers were placed on the acromia, lateral humeral epicondyle, radial styloid process, and ulnar styloid process of all the subjects (both sides), and two markers were placed on the boat [one was 50 cm ahead from the head of cockpit (front point) and the other was 20 cm behind the rear of the cockpit (rear point)]. All the trials were performed twice and under good weather conditions with no wind and very few waves. All the images were caught on the right side, and the average data of two measurements were used.

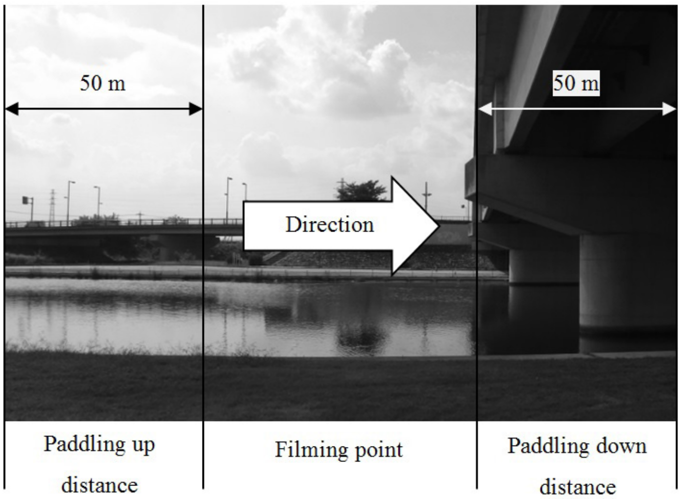

Figure 1: Setup.

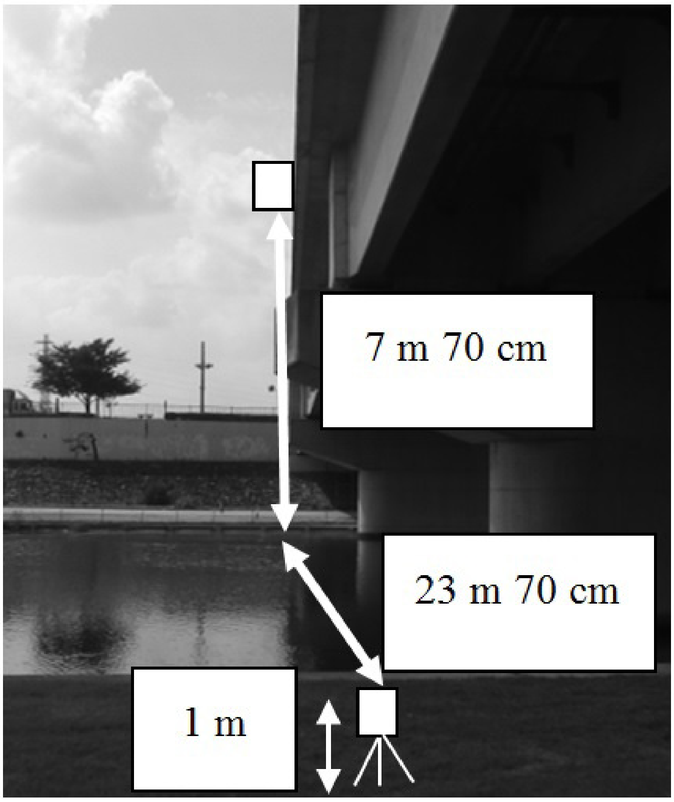

Figure 2: Installation position of cameras.

From each moving image, two phases were extracted in accordance with the report of McDonell et al. [10]: one is the catch phase, when the paddle has landed on water, and the other is the middle phase, when the paddle is upright in water. Between these two phases, it is thought that paddling skills of each kayaker might influence the movements, but this period is the most required the power of moving the boat forward, which is important for good performance and also provocation of disorders. In both the phases, five angles were measured: 1. The angle of trunk rotation on the horizontal plane was the angle between the line connecting both the acromia and the perpendicular line to the line connecting the front point and rear point of the boat. 2. The angle of shoulder horizontal flexion on the horizontal plane was the angle between the line connecting both the acromia and the line connecting the acromion and lateral humeral epicondyle. 3. The angle of shoulder flexion on the sagittal plane was the angle between the vertical line through the acromion and the line connecting the acromion and lateral humeral epicondyle. 4. The angle of elbow flexion on the sagittal plane was the angle between the line connecting the acromia and lateral humeral epicondyle and the line connecting the lateral humeral epicondyle and radial styloid process. 5. The angle of trunk flexion on the sagittal plane was the angle between the line connecting the rear point of the boat and the acromion and the vertical line through the rear point of the boat. Formfinder (FORMFINDER Lab. Co.) was used as the image analyzer software.

Statistical Analysis

Spearman's rank correlation coefficient was used to statistically evaluate the relationship between each physical function data and movement analysis data in the two phases. The significance level was set at 5 %, and SPSS 22.0J for Windows was used as the statistical analysis software.

Results

The results of physical flexibility evaluation are shown in Table 1, and the results of movement analysis are shown in Table 2. No significant difference in body function between the left and right sides was observed.

Results of the correlation between angle data from the movement and physical flexibility data are shown in Table 3. In the catch phase, there was a moderate-to-strong positive correlation between the trunk rotation angle (physical flexibility) and shoulder horizontal flexion angle (right: r = 0.686, left: r = 0.844). In addition, there was a moderate-to-strong negative correlation between the hip internal rotation angle (physical flexibility) and shoulder horizontal flexion angle (right: r = −0.784, left: r = −0.676). Further, there was a strong negative correlation between SLR and the shoulder flexion angle (right: r = −0.840, left: r = −0.816). In the middle phase, there was a moderate negative correlation between the trunk rotation angle and SLR (right: r = −0.495, left: r = −0.520) and a similarly moderate negative correlation between the trunk flexion angle and SLR (right: r = −0.595, left: r = −0.603).

Table 1: Results of physical function data (average ± SD).

Range of trunk rotation (°)	right	48.8 ± 8.2
	left	46.2 ± 7.8
Hip joint internal rotation (°)	right	43.9 ±11.2
	left	40.2 ± 9.8
Hip joint external rotation (°)	right	64.2 ± 5.8
	left	64.6 ± 7.1
Finger floor distance (cm)		7.8 ± 11.2
Heel buttock distance (°)	right	143.2 ± 14.8
	left	144.1 ± 15.2
Straight leg raise (°)	right	78.2 ± 8.7
	left	80.2 ± 11.2

SD = Standard Deviation

Table 2: Results of angles measurement (°, average ± SD).

Phase	Trunk rotation	Shoulder horizontal flexion	Shoulder flexion	Elbow flexion	Trunk flexion
Catch	36.8 ± 7.2	134.6 ± 4.7	74.5 ± 3.2	148.6 ± 14.7	16.1 ± 3.7
Middle	16.7 ± 6.1	126.8 ± 8.9	41.8 ± 3.8	154.6 ± 11.4	10.4 ± 3.2

SD = Standard Deviation

Table 3: Correlation between angle data and physical function data (value means "r").

Rt		Trunk rotation		Hip internal rotation		Hip external rotation		FFD	HBD		SLR	
		Lt	Rt	Lt	Rt	Lt		Rt	Lt	Rt	Lt	
Catch phase	TR	0.575	0.615	−0.491	−0.564	−0.308	0.007	0.008	−0.311	−0.266	−0.265	−0.092
	SHF	0.686*	0.844**	−0.784**	−0.676*	0.071	0.334	0.083	−0.315	−0.264	−0.261	−0.001
	SF	0.017	−0.011	0.241	0.381	0.129	0.394	0.480	0.490	0.468	−0.840**	−0.816**
	EF	0.224	0.121	−0.031	−0.132	−0.211	0.019	−0.238	−0.159	−0.101	−0.196	−0.245
	TF	0.033	0.071	0.241	0.412	0.284	0.260	0.298	−0.038	−0.075	−0.154	−0.232
Middle phase	TR	0.382	0.389	−0.008	0.184	0.233	0.137	0.540*	0.174	0.172	−0.495*	−0.520*
	SHF	0.168	−0.200	0.284	0.212	0.076	0.129	−0.199	0.381	0.462	0.168	0.128
	SF	0.018	−0.152	0.402	0.172	0.193	0.240	0.282	0.425	0.348	0.265	0.115
	EF	0.053	−0.130	−0.267	−0.116	0.014	0.164	−0.075	−0.283	−0.334	−0.304	−0.331
	TF	0.047	−0.006	0.105	0.278	0.272	0.393	0.325	0.311	0.266	−0.595	−0.603*

*: $p < 0.05$, **: $p < 0.01$

TR = Trunk Rotation; SHF = Shoulder Horizontal Flexion; SF = Shoulder Flexion; EF = Elbow Flexion; TF = Trunk Flexion; FFD = Finger Floor Distance; HBD = Hip Buttock Distance; SLR = Straight Leg Raise; Rt = Right Side; Lt = Left Side

Discussion

Relationship Between the Shoulder Horizontal Flexion in the Catch Phase and the Trunk Rotation Angle and Hip Inner Rotation Angle

The larger the trunk rotation angle was and the smaller the hip inner rotation angle was, in the catch phase, the larger the shoulder horizontal flexion angle showed. In the catch phase, the shoulder joint is flexed; however, if the range of these flexion movements is too large, the distance between the position of the paddle and trunk increases, and it is thus possible to overload the shoulder joint. In addition, the reduction of hip internal rotation movement may be a factor in the restriction of pelvic movement that leads to trunk over-rotation and then increases shoulder horizontal flexion, thereby emphasizing on the positive correlation between trunk rotation and shoulder horizontal flexion in the same direction of movement.

Kayaking movement appears to consist mainly of the movements of the upper extremities and trunk; however, movements of the lower trunk and extremities are also very important and can serve as the driving force [11]. In terms of performance improvement, movements of the lower trunk and extremities are important to produce power and are also thought to be required to prevent any disorder in order to produce a smooth kinetic chain that does not lead to an excessive burden on the upper trunk and extremities. The results of the present study indicate that the movement limitation of hip internal rotation, including the pelvis and hip joint, may cause excessive movement of the upper trunk and extremities, which might conceivably lead to an excessive burden on the shoulder joints and lumbar spine.

Relationship Between SLR and Shoulder Flexion in the Catch Phase and Trunk Flexion and Rotation in the Catch Phase

SLR shows the tightness or shortening of the posterior muscles of the thigh, particularly hamstrings; therefore, in the present study, as the value of SLR was smaller (as the hamstrings were tighter), the shoulder flexion angle in the catch phase was larger, and the trunk flexion and rotation angle in the middle phase were larger. Large flexion of the shoulder in the catch phase may be caused by non-smoothly movement of the arm while reaching forward. This problem was thought to be caused by insufficient pelvic posterior tilting in the forward direction due to the shortening of hamstrings. Excessive shoulder flexion in the catch phase may make the scapula fixed in the external rotated position and inhibit smooth movement of the scapula and upper trunk. Large trunk rotation in the middle phase means that the rotated trunk in the catch phase has not returned sufficiently. In the middle phase, a paddle is located perpendicular to the water surface and is the closest to the paddler; therefore, sufficiently returned trunk rotation is required to lessen the burden on the shoulder joint. This insufficiently returned trunk rotation may have also lead to excessive trunk flexion and excessive trunk rotation after the middle phase.

It is well known that pelvic posterior tilting due to the tightness or shortening of hamstrings can cause various disorders [13,14]. The results of the present study indicate that pelvic posterior tilting in the kayak cockpit may inhibit smooth trunk rotation and cause excessive movement of the trunk and shoulders. Despite information from only the disorder history check and physical function tests, there are some reports showing no relationship between paddling movements and low back pain and SLR or hamstrings tightness [15]. The present study examined only the characteristics of kayaking movement; therefore, the results due to the tightness or shortening of hamstrings as well as multilateral aspects should be considered.

Limitation of this Study

At first, there are a lot of points remained to be reviewed in the measurement method. It is needed to clarify whether obtained values in this study could show the targeted movements accurately, for example the length of each paddle might influence the shoulder flexion angle and the height of each seat might influence the movements of pelvis and hip joint. In addition, subjects in this study were very young belonging to their high-schools, who were novices and had not enough experienced kayaking. So the results were possible to be influenced by novice specific movements. It is needed to compare to the movements of experts.

Knowledge of the Present Study and Future Research

Insufficient flexibility of hip internal rotation and hamstrings may cause excessive movement of the shoulder and trunk. It has been reported that unfavorable repeated movement triggered inflammation or pain [16]; therefore, the results of the present study may indicate a risk of shoulder or trunk disorders. Insufficient trunk function and tightness of hamstrings are thought to be high risk factors of back pain [17], and the present study emphasizes on the importance of these factors for the prevention of disorders in kayaking movement. López-Miñarro et al. suggested that postural training and instructions are important for canoe athletes [18]. In the future, not only physical function but also posture, muscular balance, and other aspects should be included in the examination of its relevance to movement.

However, the aforementioned data pertain to only two points of kayaking movement (catch phase and middle phase); therefore, it is essential to determine the movements and their timing before and after each phase with regard to the change in rotation of the pelvis and hip joint. In addition, the measurement methods used in the present study did not fully capture the movement. It is a challenging task to perform measurements under limited circumstances on water; however, it may be necessary to clarify the significance and validity of each measurement.

Conclusion

In the present study, the relationship between kayaking movement on water and physical flexibility was clarified. The flexibility of hip inner rotators and hamstrings was thought to be a factor of excessive movement of the shoulder and trunk.

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