Lumbar Alignment and Trunk Muscle Activity during the Underwater Streamline Position in Collegiate Swimmers

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Abstract

We investigated the relationship between lumbar alignment and trunk muscle activities during the underwater streamline position. Twenty-two male collegiate swimmers participated in the study. Firstly, spinal alignments of 22 participants were evaluated during standing and underwater streamline position using image analysis. Thoracic kyphosis angle and lumbar lordosis angle were measured to evaluate the spinal alignment. Secondly, eleven swimmers participated to the continued investigation: 6 participants who had the smallest alteration in lumbar lordosis between the two positions (these became the smallest group) and 5 participants who had the largest alteration (these became the largest group). Their spinal alignments and their trunk muscles activities were measured during two positions in the same manner as was performed in the first experiment. The muscles activities were measured using surface electromyography. As a result, a significant difference between the two groups was observed in the internal oblique/transversus abdominis muscle activities during the underwater streamline position ($p<0.05$). Therefore, it was considered that the internal oblique/transversus abdominis muscle activities were related to the magnitude of the lumbar lordosis alteration during the underwater streamline position.

Introduction

In swimming, streamline position is a fundamental posture in all swimming strokes. Streamline position is characterized as a streamline-shaped body posture with both arms elevated and is essential to maintain a horizontal straight position for less resistance underwater (Maglischo, 2003). Lyttle, Benjanuvatra, Blanksb and Elliott (2002) reported that the streamline position reduces a swimmer's passive drag and improves the swimming performance.

While keeping a streamline position is important for all strokes, Wanivenhaus, Fox, Chaudhury and Rodeo (2012) reported that all swimming strokes maintained hyperextension of the lower back to achieve a streamlined position, and they suggested that hyperextension is exaggerated in the "undulating" style of breaststroke and butterfly that repetitively load the posterior structure of the lumbar spine. Repetitive lumbar hyperextension during swimming stroke is reported to result in low back injury (Pollard & Fernandez, 2004; Gerrard, 2008). Thereby, streamline position can be considered as a factor for the development of low back pain in competitive swimmers. Low back pain is a common symptom in competitive swimmers (Pollard & Fernandez, 2004; Kaneoka, Shimizu, Hangai, Okuwaki, Mamizuka, Sakane & Ochiai, 2007; Wolf, Ebinger, Lawler & Britton, 2009), therefore, it is important to avoid a hyperextension of the lower back during streamline position to prevent low back pain.

In clinical medicine, the evaluation of lumbar alignment is the first step for the prevention of lumbar disorders (Lance & James, 2000; Milosavljevic, Milburn & Knox, 2007). However, to our knowledge, there are no study that measured the lumbar alignment during underwater movement. If a swimmer's lumbar alignment during underwater streamline position can be investigated, it may be possible to evaluate whether the swimmer has a hyperextension position or not.

On the other hand, trunk muscle activity is considered to be an important factor to control lumbar alignment (Panjabi, 1992), therefore, trunk muscle activity may influence the control of lumbar alignment during streamline position. Previous study indicated that to control spinal stability and to strengthen trunk muscle is important for competitive swimmers in order to prevent lumbar disorders (Kenal & Knapp, 1996). Many previous studies investigating muscle activity during swimming were evaluated by electromyography (EMG) since the 1930s (Clarys, 1982), but few studies have investigated trunk muscle activity during streamline position. Most of the studies reported upper limb muscle activity related to propulsive force (Clarys, 1982; Pink, Perry, Browne, Scovazzo & Kerrigan, 1991; Rouard & Clarys, 1995; Wakayoshi, Moritani, Mutoh, Miyashita, 1994; Caty, Aujouannet, Hintzy, Bonifazi, Clarys, & Rouard, 2007), and did not focus on the trunk muscle activity related to keeping the streamline position.

The purpose of this study was to evaluate spinal alignment during the streamline position in competitive swimmers and to clarify the relationship between lumbar alignment and trunk muscle activity during the streamline position.

Methods

Participants

Participants were 22 male collegiate competitive swimmers (height: 1.75± 0.05 m, weight: 69.5±5.2 kg, athletic career: 13.1±3.1 years). The participants were made fully aware of the risks, benefits, and stresses of the study and their informed consent was obtained. This study was performed under the approval of the research ethics committee of the university.

Procedures and Tasks

This study was divided into Experiment 1 and Experiment 2.

In Experiment 1, spinal alignments were measured for 22 participants who performed 2 tasks: keeping a standing position and an underwater streamline position. The standing position was defined as a neutral position at rest on land, and was set for investigating the effect of individual alignment. The streamline position was defined as the body position during maximal voluntary horizontal gliding in water. The participants were instructed not to breath during the underwater streamline position for excluding the effect of breathing which may influence the trunk muscles activity.

After Experiment 1, eleven participants participated to further experiment. They were selected from the original 22 participants, according to the difference of lumbar lordosis between the standing position and the streamline position. The five members with the largest difference between the two positions became the largest group and the six members with the smallest difference between the two positions became the smallest group. These 11 participants participated in Experiment 2 which investigated the participant's trunk muscles activities during the standing position and the streamline position.

These experiments were performed at indoor 50 m pool. Throughout these experiments, the water temperature was set to 28.4±1.4 degree. Three trial data were collected in each experiment.

Spinal alignment measurements

Sagittal alignment of the spine was measured referring to Obayashi and Urabe (2008) and analyzed by images taken on the sagittal plane during the two tasks. During the standing position, static images were taken by a digital camera (EX - H20G, CASIO Inc.) placed on the right side at 10 m away from the participant on land. During the underwater streamline position, video images were taken by an underwater video camera (WUC-265, Nihon Jimu Kouki Inc.). The video camera was set on the deck at 5 m away from the start line.

One of the frames of the video during the streamline position was extracted when targets were located in the center of the angle of view. The alignments were measured by using the following anatomical landmarks. The 5 spinous processes were chosen as landmark points, and the lumbar lordosis angle and the thoracic kyphosis angle was defined as shown in Figure 1. Cone-shaped markers were placed on the spinous processes. Each marker's height was 4.5 cm and they were set on each location as vertical as possible. Shoulder flexion is reported to influence thoracic alignment and lumbar alignment (Kapandji, 1982). Therefore, shoulder angle was measured during underwater streamline position. The olecranon, acromion and lower end of the tenth rib were marked using plastic tapes and the shoulder angle was defined as shown in Figure1.

The images taken in each experiment were saved to a computer and analyzed using image analyzing software (Image J, National Institutes of Health) to calculate each angle. These spinal angles were defined as the mean value of three trials.

Before performing this study, the accuracy of the image analysis of alignment during the streamline position was verified by a pilot study. We constructed an L shaped calibrator with side lengths of 10 cm each, and static images and video images of this calibrator were taken on land and under water using the same methods as the main study. On land, this calibrator was set at a height of 1.2 m and 10 m from the camera. In water, the calibrator was set at a 0.6 m water-depth and 5 m from the start line. The images were saved to a computer and analyzed using the same image analyzing software. Consequently, the calculated mean angles of the calibrator were 89.6 degree on land,

and 90.8 degree under water. Therefore, the measurement error showed less than 1 degree, and the accuracy of this study's method were considered to be acceptable.

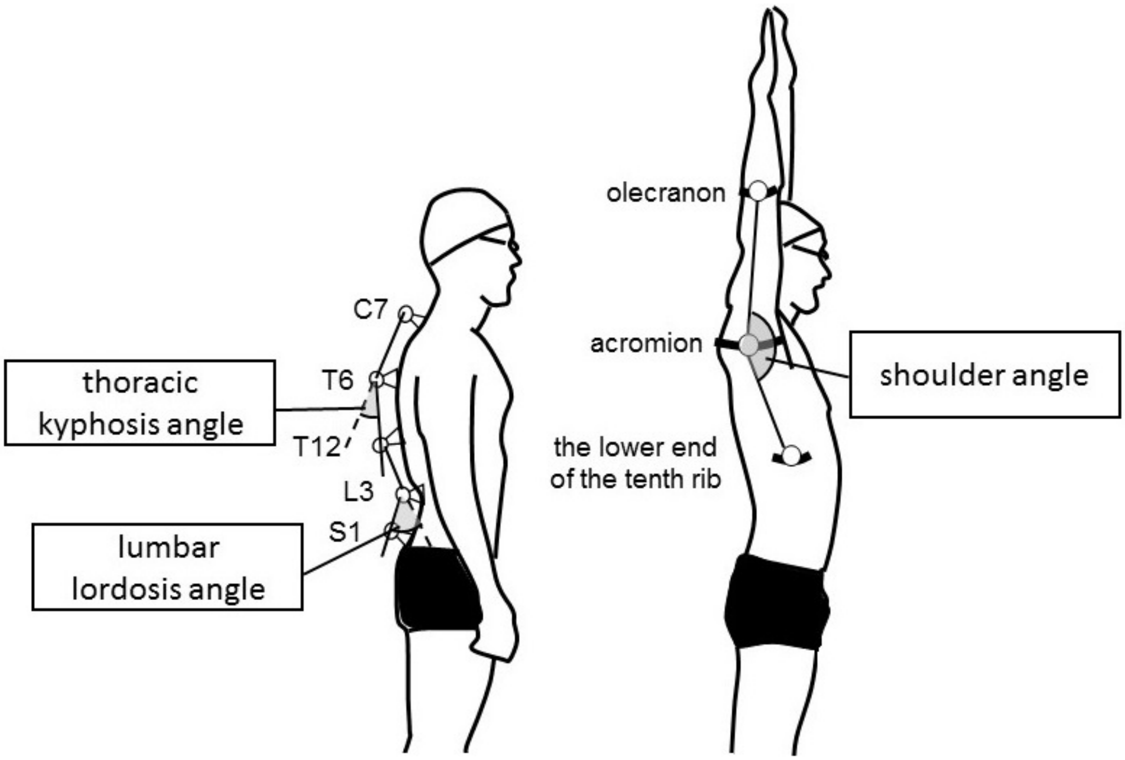

Figure 1. Definition of the thoracic kyphosis angle, the lumbar lordosis angle and the shoulder angle. The 5 spinous processes were chosen as landmark points (the 7th cervical vertebrae, C7; the 6th thoracic vertebra, Th6; the twelfth thoracic vertebra, Th6; the 3rd lumbar vertebra, L3; the 1st sacral vertebra, S1). The lumbar lordosis angle was defined as the angle between the base line connecting Th12 to L3 and the variant line from L3 to S1. The thoracic kyphosis angle was defined as the angle between the base line of C7 to Th6 and the variant line of Th6 to Th12. The shoulder angle was defined as the angle between the base line of the acromion to the lower end of the tenth rib and the variant line of the acromion to the olecranon.

EMG measurements & Data processing

The EMG data was measured at a sampling frequency of 1000 Hz, with 16-bit analogue to digital conversion (Biolog system, S&ME Inc.). The EMG signal of 6 muscles (rectus abdominis, RA; external oblique, EO; internal oblique / transverse abdominal, IO/TrA; erector spinae, ES; gluteus maximus, Gmax; rectus femoris, RF) was recorded from the left side of the body using bipolar (inter-electrode distance of 3 cm) disposable Ag-AgCl circular electrodes with a wireless EMG logger. The locations of the electrodes were determined according to recommendations of the SENIAM project (Hermens, Freriks, Merletti, Stegeman, Blok, Rau and Disselhorst-Klug, 1999) and the study of Park and Lee (2010). Before electrode fixation, the skin surface was shaved, abraded, and cleaned with alcohol. The electrodes were waterproofed by covering them with water resistance tape to prevent water entering the electrodes (Figure 2). For the amplifier, input impedance was >200MΩ, a common mode rejection ratio was >110db. To synchronize EMG data and video, a LED light / electronic trigger was marked simultaneously on the video and the EMG recordings. The EMG data during the standing position was recorded over 5 seconds and utilized to calculate the total amount of each muscle activity. The EMG data during the streamline position was collected from when the top of a participant's toe passed through the range of 4 m to 6 m by using recorded video images.

In order to normalize the activity potential of the individual muscles, their maximal voluntary contraction (MVC) were measured against manual resistance according to the recommendation of Kendall, Kendall and Wadsworth (1971) and Ferreira, Ferreira and Hodges (2004). Manual resistance was applied gradually, until a maximum effort was obtained, and then it was held for an additional 5 seconds. MVC measurements were tested twice for each muscle, with a brief rest period. The subjects were familiarized with the MVC test procedure to produce the maximal force output prior to each measurement session. The instructors provided verbal encouragement to motivate the subjects to achieve maximal contraction levels.

The EMG data were filtered by the band-pass filter between 20 Hz and 500 Hz using by m-BIOLOG2 software (S&ME Inc.). The filtered EMG data were analyzed after calculating the Root Mean Square (RMS). The RMS of experimental trial and 5-second MVC were calculated on a 100 ms window of data (Kaneda, Sato, Wakabayashi & Nomura, 2009). The peak RMS values of each muscle MVC were selected as a standard for normalizing (100%). The RMS data for the two positions were normalized by the peak RMS during MVC (%MVC), and the amount of muscle activity was reported by %MVC. The amount of each muscle activity during each position was defined as the mean value of 3 trials.

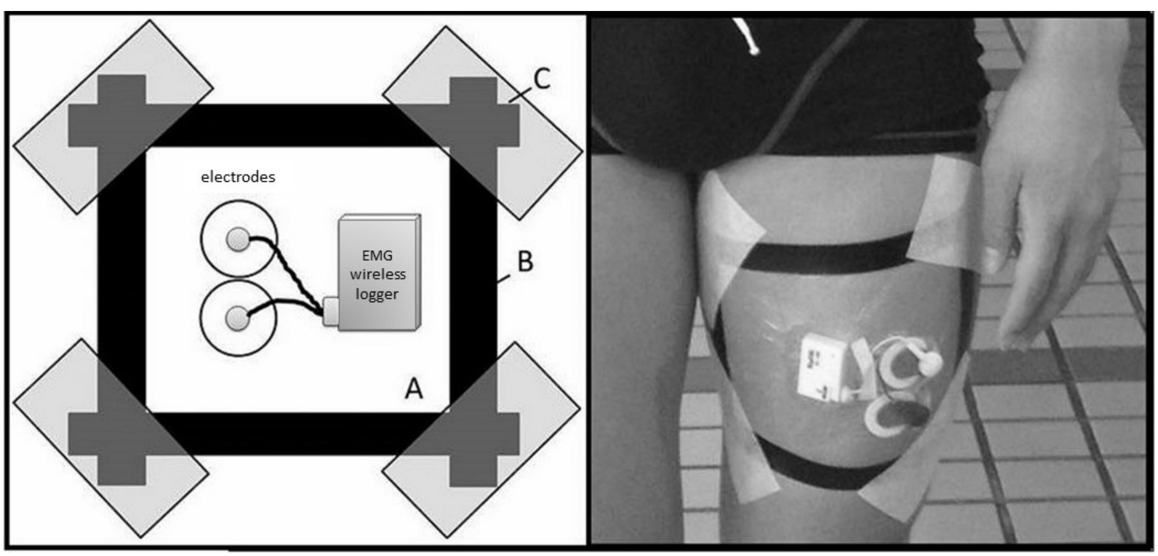

Figure 2. The waterproofing procedures for each set of electrodes consisted of 3 steps. First, surface electrodes and a wireless EMG logger were covered with a transparent dressing tape (A). Second, edges of the dressing tape were reinforced with plastic tape (B). Finally, the adherence bandage attached the corners to prevent peeling of these tapes (C).

<u>Analysis</u>

All data are reported as mean ± SD. The normality of all data was confirmed using Shapiro-Wilk test. In Experiment 1, the thoracic and lumbar alignment data were compared between the standing position and the streamline position using the paired t-test. The relationship of the thoracic kyphosis angle or lumbar lordosis angle between the standing position and the underwater streamline position, and the relationship between the shoulder angle and the thoracic kyphosis angle or lumbar lordosis angle during underwater streamline position were analyzed using Pearson's correlation coefficient. The alteration of lumbar lordosis angle (Δ lumbar lordosis angle) was calculated as 'value in the streamline position minus those in the standing position'. In Experiment 2, the alteration of the alignment data (Δ thoracic kyphosis angle and Δ lumbar lordosis angle) and the alteration of %MVC value (Δ %MVC value) were calculated as well as Experiment 1. The alignment data and the %MVC data during the streamline position were compared between two groups using the Mann–Whitney U test. The statistical significance level was set at 5% in this study ($p < .05$). Effect sizes between the two positions in Experiment 1 and between the two groups in Experiment 2 were computed by Cohen's d and r (correlation coefficient), respectively. The effect size was considered small if $0 \leq |d| \leq .20$ or $0 \leq |r| \leq .10$, medium if $.20 < |d| \leq .50$ or $.10 < |r| \leq .30$, and large if $|d| > 0.5$ or $|r| > .50$ (Cohen, 1988; Field, 2005).

Results

In Experiment 1, significant differences between the two positions were identified in the comparisons of the lumbar lordosis angle (standing position: 10.8±4.9 degree vs streamline position: 15.6±4.2 degree; $p < 0.001$; ES = 1.05) and the thoracic kyphosis angle (standing position: 21.8±5.2 degree vs streamline position: 11.4±5.3 degree; $p < 0.001$; ES = 1.98). The shoulder angle during underwater streamline position was 166.2±4.8 degree. As the results of correlation analysis, significant positive correlations between the standing position and the underwater streamline position were observed on thoracic kyphosis angle ($r = 0.586$, $p = 0.004$) and on lumbar lordosis angle ($r = 0.770$, $p < 0.001$). However, no significant correlation were shown between the shoulder angle and the thoracic kyphosis angle ($r = -0.410$, $p = 0.058$), and between the shoulder angle and the lumbar lordosis angle (r = -0.198, p = 0.377). The Δ lumbar lordosis angles were calculated (mean±SD = 4.9±3.1 degree; median = 4.6 degree) and the normality was ensured by the result of Shapiro-Wilk test (p ≥. 05). Based on the results of the alterations of lumbar lordosis angle, the fourteen participants were selected as the largest group and the smallest group.

Table 1 shows a comparison of the mean difference of spinal alignments between the smallest and largest groups measured in Experiment 2. Significant differences between the two groups were identified in the comparison of the lumbar lordosis angle during the streamline position (largest group: 20.5±3.6 degree vs smallest group: 13.6±4.6 degree; p = 0.018; ES = 0.72) and in the comparison of the Δ lumbar lordosis angle (largest group: 6.8±1.2 degree vs smallest group: -2.3±3.3 degree; p = 0.006; ES = 0.83). As the result of shoulder angle, no significant difference was shown between two groups (largest group: 163.6±6.3 degree vs smallest group: 165.4±4.1 degree; p = 0.714; ES = 0.11). The results of the amount of muscle activity in each group are shown in Table 2. A significant difference between the two groups was identified only in a comparison of the IO/TrA during streamline position (largest group: 7.6±6.4% vs smallest group: 29.5±14.0%; p = 0.006; ES = 0.83) and in the comparison of the Δ %MVC value of IO/TrA (largest group: 3.6±4.7% vs smallest group: 21.9±12.8%; p = 0.045; ES = 0.61).

Table 1. Results of the thoracic kyphosis angle, the lumbar lordosis angle and the shoulder angle measurements in Experiment 2.

Variable			Largest group	Smallest group	Significance (*p*)	Effect size (*r*)
Streamline	thoracic kyphosis angle	(degree)	14.2±3.6	11.8±4.6	. 522	. 19
	lumbar lordosis angle	(degree)	20.5±3.6	13.6±4.6	. 018	. 72
	shoulder angle	(degree)	163.6±6.3	165.4±4.1	. 714	. 11
△ thoracic kyphosis angle		(degree)	-10.7±3.9	-12.1±6.7	. 465	. 22
△ lumbar lordosis angle		(degree)	6.8±1.2	-2.3±3.3	. 006	. 83

deg: mean ±s

Table 2. Results of the %MVC value during streamline position in Experiment 2.

Variable		Largest group	Smallest group	Significance (*p*)	Effect size (*r*)
%MVC Value	(%)				
RA		1.6±3.1	5.2±3.9	. 465	. 22
EO		2.7±11.9	14.1±14.1	. 855	. 06
IO/TrA		7.6±6.4	29.5±8.4	. 006	. 83
ES		2.3±4.7	12.5±7.9	. 410	. 25
Gmax		2.0±2.5	4.8±8.4	. 410	. 25
RF		2.2±4.7	7.1±2.4	. 360	. 28
Δ %MVC Value	(%)				
RA		2.2±3.0	3.6±2.8	. 714	. 11
EO		8.2±10.9	11.3±13.9	. 784	. 08
IO/TrA		3.6±4.7	21.9±12.8	. 045	. 61
ES		6.1±5.7	10.3±6.7	. 361	. 28
Gmax		0.7±4.5	2.8±9.0	. 855	. 06
RF		5.0±4.3	4.9±1.4	. 584	. 17

%: mean±s

Discussion

This present study evaluated the spinal alignment during the streamline position in 22 competitive swimmers and additionally investigated the relationship between lumbar alignment and trunk muscle activity during the streamline positions through each experiment. In this study, we found the changes of spinal alignment caused by keeping a streamline position, and we additionally found the difference of IO/TrA activity during the streamline position between largest group and smallest group.

The results of Experiment 1 showed that the streamline position induced an increase of lordosis in the lumbar spine. The inducing lumbar extension during streamline position may be caused by the arms elevating position. Kapandji (1982) demonstrated that the lumbar extend compensatory when the shoulder joint flex over 120 to 180 degree. According to this results, it was considered that the inducing lumbar extension during streamline position was caused by their arm elevation in this study.

From the results of correlation analysis in Experiment 1, strong positive correlations were observed between the two absolute spinal angles during a standing and a streamline position. This suggested that a poor thoracic and lumbar alignment on land are related to a poor thoracic and lumbar alignment during underwater streamline position. Therefore, it is considered that the measurement of thoracic and lumbar alignment on land is good for evaluating a poor thoracic and lumbar alignment during underwater streamline position.

The results of Experiment 2 showed that the difference of mean Δ lumbar lordosis angle between each group was approximately 10 degree. In general, the lumbar maximal extension angle has been reported to be approximately 50 degrees (Sahrmann, 2002). The 10 degree change in the lumbar lordosis angle corresponds to 20% of the maximal lumbar extension angle. Surprisingly, large difference of the inducing lumbar extension keeping the streamline position was observed in collegiate male competitive swimmers who had athletic career over 10 years. From this result, it was indicated that, even with the skilled swimmers, lumbar alignment during the streamline position should be evaluated and improved.

As results of the shoulder angle investigation in Experiment 2, no significant difference between the two groups was observed. From this result, it was suggested that the shoulder angle during underwater streamline position was not related to the Δ lumbar lordosis angle. Also, as the result in Experiment 1, no significant correlation were shown between the shoulder angle and the lumbar lordosis angle. Therefore, it was considered that the shoulder angle was not related to a poor lumbar alignment during underwater streamline position in the population of this study.

We demonstrated that the muscle activity of IO/TrA during the streamline position were significantly different between the two groups in the results of Experiment 2. Furthermore an increase of lumbar lordosis may be related to deteriorated muscle activity of the IO/TrA. Carman, Blanton & Biggs (1972) reported that the pelvis moves backward when the IO contracts, and Day, Smidt & Lehmann (1984) explained the posteriorly tilted pelvis contributes to the lumbar lordosis decrease. On the other hand, the TrA controls abdominal internal pressure and segmental stability of the lumbar spine (Cholewicki & VanVliet, 2002). As the results of Experiment 1, keeping the streamline position induced an increase of lordosis in the lumbar spine. Therefore, it was considered that smallest group might have controlled lumbar alignment by pelvic backward tilting and increment of abdominal internal pressure that are related to IO/TrA activity. Consequently, it was indicated that the increment of IO/TrA activity in the smallest group contributed to keeping a straight lumbar alignment and may have the possibility to remove the mechanical stress of lumbar segments.

Based on the results of this study, we have two recommendations to swimmers and coaches; 1) the measurement of absolute thoracic and lumbar alignment on land is good for evaluating a poor thoracic and lumbar alignment during underwater streamline positon, 2) a swimmer with lumbar hyperextension should obtain a function to activate IO and TrA during underwater streamline position by conducting specific exercise (e. g. abdominal hollowing or abdominal drawing-in maneuver).

Conclusion

In this study, we evaluated the spinal alignment during the streamline position in competitive swimmers and investigated the relationship between lumbar alignment and trunk muscle activities during the underwater streamline position. Consequently, we found that streamline position induced an increase of lordosis in the lumbar spine. Also, the absolute thoracic kyphosis and lumbar alignment during underwater streamline position was related to the absolute thoracic kyphosis and lumbar alignment on land. Furthermore, it was considered that the IO/TrA activities were related to the magnitude of the lumbar lordosis alteration during the underwater streamline position. Further study is warranted to evaluate IO/TrA activity and investigate whether the spinal alignment would change when muscle activity changes during an underwater streamlined position.

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