



Original Article

Relationship between isometric shoulder strength and arms-only swimming power among male collegiate swimmers: study of valid clinical assessment methods

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Abstract. [Purpose] The purpose of the present study was to confirm the relationships between shoulder strength (extensor strength and internal rotator strength) of the abducted position and swimming power during arm-only swimming. [Subjects and Methods] Fourteen healthy male collegiate swimmers participated in the study. Main measures were shoulder strength (strength using torque that was calculated from the upper extremity length and the isometric force of the abducted position) and swimming power. [Results] Internal rotation torque of the dominant side in the abducted external rotated position ($r=0.85$) was significantly correlated with maximum swimming power. The rate of bilateral difference in extension torque in the maximum abducted position ($r=-0.728$) was significantly correlated with the swimming velocity-to-swimming power ratio. [Conclusion] The results of this study suggest that internal rotator strength measurement in the abducted external rotated position and extensor strength measurement in the maximum abducted position are valid assessment methods for swimmers.

Key words: Correlation study, Specificity, Validity

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INTRODUCTION

The crawl swimming stroke comprises a pull motion and a kick motion and consists of a catch phase, pull phase, finish phase, and recovery phase. During crawl swimming, it has been reported^{1, 2)} that the ratio of the contribution of the arm pull is more than 80% and that propulsion is generated mainly by the catch and pull phases during the pull motion. Swimming power (SP) is indicated as propulsion, and SP is calculated using the traction force (F) when pulling the resistive force equipment and swimming velocity (SV) during swimming³⁻⁵⁾. SP and swimming velocity are significantly correlated³⁻⁵⁾. Therefore, the magnitude of SP and the magnitude of the swimming velocity-to-swimming power ratio (SVPR) are considered important factors for improving swimming velocity.

During the arm pull of the stroke, one of the most important joints is the shoulder joint. Therefore, training and rehabilitation of the shoulder are important for improving athletic ability. During training and rehabilitation of the shoulder, improvement and recovery of muscular strength are important goals because the muscular strength and technique are necessary to propulsion; therefore, muscle strength measurements are performed to evaluate intervention effects. During this evaluation, a

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measurement method related to swimming performance was necessary to measure muscle strength. In relation to swimming performance and muscle strength, it was reported⁶⁾ that shoulder joint extension torque and velocity while swimming the crawl stroke for 25 m are moderately significantly correlated. However, this report focused on muscle strength measurements of shoulder extension during the neutral shoulder position and not during positions similar to those used while swimming. The relationship between the maximum SP (MSP), SVPR, and muscle strength measurements has not been sufficiently investigated. Therefore, clarifying muscle strength measurement methods related to MSP and SVPR would be beneficial for muscle strength assessments during the training process and rehabilitation process.

During the pull motion, the catch phase involves extension of the shoulder in the maximum abducted position (MAP) and the pull phase involves internal rotation in the abducted and external rotated position (AEP). The reliability of the muscle force measurements at these positions has been examined, and high reliability was reported^{7, 8)}. However, the relationship between these measurement methods and swimming performance has not been investigated; therefore, valid assessment methods have not yet been determined.

The purpose of the present study was to confirm the relationships between shoulder strength (extensor strength and internal rotator strength) in the abducted position and swimming power (MSP and SVPR) during arm-only swimming.

SUBJECTS AND METHODS

The sample size of the study was calculated as 10 using an effect size of 0.73, statistical power of 0.8, and significance level of 5%, with reference to the results of Mori et al. ($r=0.73$)⁵⁾. G*Power 3.1.9.2 statistical software was used to calculate the sample size.

Participants experienced no shoulder pain during the past 6 months and had no history of shoulder surgery. Fourteen healthy male collegiate swimmers (mean \pm standard deviation [SD]: age, 19.6 ± 1.2 years; height, 167.9 ± 6.1 cm; body weight, 64.0 ± 8.0 kg; experience, 11.4 ± 3.3 years) participated in the study. The participants were well-informed about the study both orally and in writing and provided written consent. An experienced examiner performed the muscle strength measurements. The present study was performed with the approval of the Research Ethics Committee of Kyushu Kyoritsu University (approval no. 2015-04).

The participants underwent SP measurements after muscle strength was measured. Before the trial was started, participants performed shoulder warm-up movements. The maximum isometric force was measured using a hand-held dynamometer (HHD) (Mobie MM100C; Minato Medical Science Co., Ltd., Japan); it was also used to calculate the torque. The torque was calculated using the extremity length and isometric force. The extension force (EF) of the MAP was measured at the shoulder positioned with maximum shoulder abduction, with the elbow extended, and with the forearm in a neutral position⁸⁾ (Fig. 1). The internal rotation force (IF) of the AEP was measured at the shoulder positioned with 90 degrees of shoulder abduction and 90 degrees of external rotation, with the elbow at 90 degrees of flexion, and with the forearm in a neutral position⁸⁾ (Fig. 1). During both measurements, the HHD was placed on a firm floor, and participants touched HHD with the heads of the metacarpal bones on the palm side. It was held in place by the participant's hand to prevent any improper movement during measurement. In addition, participants were in the prone position with their toes, abdomen, chest, and mentum touching the ground. During measurement of the AEP, elbow of measurement side was kept in touch with the ground. The opposite shoulder in both measurements was positioned in contact with the side of the body. Maximum isometric contractions lasting 3 seconds were measured. Three trials were performed per session, with 5 minutes of rest allowed between sessions. The examiner observed the participants to maintain proper measurement. Repeat measurements were performed when the position was changed or when an error occurred. The average value of the three trials was calculated for each measurement. Participants, measurement positions, and shoulders were chosen randomly using a computer system. The upper extremity length and forearm length were measured using a digital caliper (D-500; Niigata seiki Co., Ltd., Japan). The upper extremity length was measured from the acromial process to the distal head of the third metacarpal bone on the dorsal side. The forearm length was measured from the lateral joint line of the elbow to the acromial process to the distal head of the third metacarpal bone on the dorsal side. The extension torque (ET) of the MAP was calculated from the upper extremity length and EF. The internal rotation torque (IT) of the AEP was calculated from the forearm length and IF.

SP measurements were performed for arm-only swimming (front crawl swimming without kicking) in a 25-m indoor pool. Twenty-five meters of arm-only swimming (front crawl swimming without kicking) was performed one time and 15 m of arm-only swimming was performed three times. The 25-m swim started underwater and was recorded at 60 fps by a digital video camera (HDR-CX270V; Sony Marketing Inc., Japan) installed on the pool side. The maximum swimming velocity (MSV) was defined as the average velocity of swimming 10 m and calculated using the 20-m point and the 10-m point captured by the moving image in the 25-m swim. The 15-m swim from 5-m point to 20-m point was performed using a simple swimming power device (drag boat) developed by Mori et al⁵⁾. Participants held buoys between the thighs, fixed the joints of both feet with a rubber tube, and began the test.

The regression coefficient (a) and regression constant (b) were calculated from the regression formula (1) using each SV and F when pulling a drag boat of three load levels and no-load during crawl swimming. SP was calculated by the formula (2) using SV and F⁵⁾. The maximum value of the curve representing the relationship between SP and SV was defined as MSP⁵⁾.

$$F=a \times SV + b \quad (1)$$

$$SP=F \times SV=(aSV + b) SV=aSV^2 + bSV \quad (2)$$

The MSP divided by body weight (MSP/kg) was calculated. In addition, SVPR was calculated by formula (3).

$$SVPR=MSV/MSP/kg \quad (3)$$

Force measurements were performed on the dominant side and non-dominant side. To normalize the bilateral differences in muscle strength, the bilateral differences on the dominant side and non-dominant side were calculated as the rate of bilateral difference in muscle strength (RB) using formula (4). The rate of bilateral difference in extension torque (RBET) and the rate of bilateral difference in internal rotation torque (RBIT) were calculated.

$$RB=(D - N)/[(D + N)/2] \times 100 \quad (4)$$

D: dominant side; N: non-dominant side

The relationship between MSV and MSP was examined using Pearson's product-moment correlation coefficient. The relationship between MSP and shoulder strength was examined using Pearson's product-moment correlation coefficient. The relationship between shoulder extensor strength and shoulder internal rotator strength was examined using Pearson's product-moment correlation coefficient. The relationship between SVPR and RB were examined using Pearson's product-moment correlation coefficient. Statistical analysis was performed using R2.8.1; $p < 0.05$ was considered statistically significant. Statistically significant p-values were adjusted using Holm-Bonferroni correction^{9, 10}. Statistical analysis used torque as muscle strength. Correlation values were assessed according to the criteria of Hinkle et al.¹¹: negligible, 0.00 to 0.30; low, 0.30 to 0.50; moderate, 0.50 to 0.70; high, 0.70 to 0.90; and very high, 0.90 to 1.00.

RESULTS

The upper extremity length was the dominant side 63.8 ± 2.8 cm, the non-dominant side 64.2 ± 3.2 cm. The forearm extremity length was the dominant side 32.1 ± 1.4 cm, the non-dominant side 32.3 ± 1.3 cm. The results of shoulder muscle strength are shown in Table 1. Muscle strength was higher on the dominant side than on the non-dominant side for all participants.

The MSV and MSP were significantly correlated ($r=0.726$; 95% CI=0.318 to 0.907; $p=0.007$; high) (Table 2). During analysis of the MSP and shoulder muscle strength, internal rotation torque of the dominant side (ITD) ($r=0.85$; 95% CI=0.582

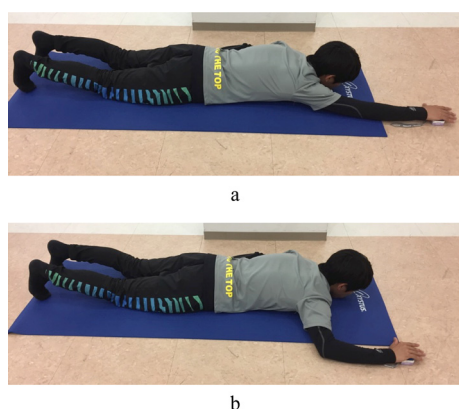


Fig. 1. Muscle strength measurement using a hand-held dynamometer.

a: The extension force of the shoulder in the maximum shoulder abducted position; b: The internal rotation force of the shoulder in the abducted and external rotated position.

Table 1. Results of the muscle strength measurement

	Mean \pm SD
EFD (N)	125.1 \pm 29.8
EFN (N)	99.5 \pm 20.1
IFD (N)	113.1 \pm 32.1
IFN (N)	102.1 \pm 29.3
ETD (Nm)	80.0 \pm 19.8
ETN (Nm)	64.2 \pm 14.7
ITD (Nm)	36.4 \pm 10.5
ITN (Nm)	33.1 \pm 10.1
RBET (%)	21.4 \pm 12.3
RBIT (%)	13.3 \pm 10.7

EFD: The extension force of the dominant side; EFN: The extension force of the non-dominant side; IFD: The internal rotation force of the dominant side; IFN: The internal rotation force of the non-dominant side; ETD: The extension torque of the dominant side; ETN: The extension torque of the non-dominant side; ITD: The internal rotation torque of the dominant side; ITN: The internal rotation torque of the non-dominant side; RBET: The rate of bilateral difference in extension torque; RBIT: The rate of bilateral difference in internal rotation torque.

to 0.952; $p < 0.001$; high), internal rotation torque of the non-dominant side (ITN) ($r = 0.76$; 95% CI = 0.384 to 0.92; $p = 0.008$; high), and extension torque of the dominant side (ETD) ($r = 0.608$; 95% CI = 0.114 to 0.861; $p = 0.042$; moderate) were significantly correlated (Table 3). The MSP and extension torque of the non-dominant side (ETN) had no significant correlation ($r = 0.211$; 95% CI = -0.36 to 0.667; $p = 0.469$). During analysis of the SVPR and RB, the SVPR and RBET were significantly correlated ($r = -0.728$; 95% CI = -0.908 to -0.322; $p = 0.006$; high). The SVPR and RBIT had no significant correlation ($r = -0.1$; 95% CI = -0.599 to 0.455; $p = 0.735$) (Table 3).

The analysis of shoulder extensor strength and shoulder internal rotator strength showed that the ETD and ETN ($r = 0.836$; 95% CI = 0.549 to 0.947; $p = 0.002$; high), the ETD and ITD ($r = 0.852$; 95% CI = 0.587 to 0.952; $p = 0.001$; high) and, the ITD and ITN ($r = 0.897$; 95% CI = 0.699 to 0.967; $p < 0.001$; high) were significantly correlated (Table 3). However, the ETN and ITN ($r = 0.432$; 95% CI = -0.128 to 0.783; $p = 0.123$), the ETD and RBET ($r = 0.423$; 95% CI = -0.139 to 0.779; $p = 0.132$), the ETN and RBET ($r = -0.137$; 95% CI = -0.622 to 0.424; $p = 0.64$), the ITD and RBIT ($r = -0.027$; 95% CI = -0.55 to 0.511; $p = 0.927$), the ITN and RBIT ($r = -0.383$; 95% CI = 0.759 to 0.185; $p = 0.176$) and, the RBET and RBIT ($r = -0.164$; 95% CI = -0.639 to 0.402; $p = 0.575$) had no significant correlation (Table 3).

Table 2. Results of the arm-only swimming measurement

	Mean \pm SD	PCC between MSV
MSV (m/s)	1.67 \pm 0.08	
MSP (W)	58.55 \pm 20.70	$r = 0.726$ ** (0.318 to 0.907)
MSP/kg (W)	0.91 \pm 0.27	$r = 0.72$ ** (0.307 to 0.905)
SVPR	1.94 \pm 0.39	

95% Confidence Interval.

The p values were adjusted using the Holm-Bonferroni correction. ** $p < 0.01$.

MSV: The maximum swimming velocity; MSP: The maximum swimming power;

SVPR: The swimming velocity-to-swimming power ratio; PCC: Pearson's product-moment correlation coefficient.

Table 3. The results of the Pearson's product-moment

		ETD	ETN	ITD	ITN	RBET	RBIT
MSP	r	0.608* (0.114 to 0.861)	0.211 (-0.36 to 0.667)	0.85** (0.582 to 0.952)	0.76** (0.384 to 0.92)	-	-
	assessment	moderate	-	high	high	-	-
SVPR	r	-	-	-	-	-0.728** (-0.908 to -0.322)	-0.1 (-0.599 to 0.455)
	assessment	-	-	-	-	high	-
ETD	r		0.836** (0.549 to 0.947)	0.852** (0.587 to 0.952)	0.764* (0.393 to 0.921)	0.423 (-0.139 to 0.779)	-
	assessment		high	high	high	-	-
ETN	r			0.494 (-0.05 to 0.812)	0.432 (-0.128 to 0.783)	-0.137 (-0.622 to 0.424)	-
	assessment			-	-	-	-
ITD	r				0.897** (0.699 to 0.967)	-	-0.027 (-0.55 to 0.511)
	assessment				high	-	-
ITN	r					-	-0.383 (-0.759 to 0.185)
	assessment					-	-
RBET	r						-0.164 (-0.639 to 0.402)
	assessment						-

95% Confidence Interval.

The p values were adjusted using the Holm-Bonferroni correction. * $p < 0.05$, ** $p < 0.01$.

MSP: The maximum swimming power; SVPR: The swimming velocity-to-swimming power ratio; ETD: The extension torque of the dominant side; ETN: The extension torque of the non-dominant side; ITD: The internal rotation torque of the dominant side; ITN: The internal rotation torque of the non-dominant side; RBET: The rate of bilateral difference in extension torque; RBIT: The rate of bilateral difference in internal rotation torque.

DISCUSSION

In the present study, MSV and MSP were significantly correlated ($r=0.726$; high). Mori et al.⁵⁾ reported that the correlation coefficient between MSV and MSP was 0.73. The results of the present study were similar to those of previous studies, thus supporting their validity. The correlation coefficients between MSP and ITD and between SVPR and RBET were 0.85 and -0.728 , respectively. The number of participants calculated with an effect size of 0.728, detection power of 0.8, and significance level of 5% was 10. Therefore, the sample size of the present study was valid.

ITD ($r=0.85$; high), ITN ($r=0.76$; high) and ETD ($r=0.608$; moderate) were significantly correlated with MSP and were assessed as high or moderate. In addition, the ITD may be the most important measurement method, because the ITD and ITN and, the ETD and ITD were found to have a high correlation. This result showed that the evaluation using internal rotator strength measurement in the AEP is a suitable method for swimmers. This may be important information for strength training and improving propulsion.

RBET ($r=-0.728$; high) was significantly correlated with SVPR and was assessed as high. This result shows that measurement of MAP extensor strength is a suitable method for swimmers because the MAP can evaluate muscle strength related to SVPR. In addition, because the magnitude of RBET has a negative relationship with SVPR, it is possible it has a negative influence on SVPR, such as decreased propulsion. However, because this research only analyzed relationships, further studies are necessary to elucidate mechanisms and technical aspects that have a negative influence.

Measurements for athletes should be easy to perform and appropriate for their sports performance. The lack of stabilization¹²⁾ and inadequate tester strength^{13, 14)} reported as measurement errors of the HHD in past studies indicated that experience and examiner bias did not affect measurement errors because, in the present study, the examiner was not involved in holding the HHD; the HHD was stabilized on the floor^{7, 8)}. Therefore, these measurement methods are simple and have high reliability because they are not affected by experience or examiner bias. Additionally, these measurement methods are similar to those for the catch phase and pull phase; therefore, they may be swim-specific methods.

Athletes with a shoulder injury have decreased propulsion because of decreasing shoulder strength. Therefore, evaluating improvement of shoulder joint muscle strength is necessary to improve MSP and SVPR for swimming. This study revealed that ITD and RBET are related to MSP and SVPR, suggesting that evaluating muscle strength improvements using internal rotator strength measurement in the AEP and extensor strength measurement in the MAP is reasonable for swimmers. Furthermore, the results of this study could contribute to the creation of swim-specific strength training programs.

This study was limited because the athletic ability of participants was limited. In addition, this research focused on the pull motion but not on swimming including the kick motion. Future studies targeting athletes of various ages and athletic levels and more swimming research are necessary.

The results of this study suggest that internal rotator strength measurement in the AEP and extensor strength measurement in the MAP are valid assessment methods for swimmers. These measurement methods have high validity and reliability. They are beneficial for muscle strength assessment during the training process because they can help improve MSP. They are also beneficial during the rehabilitation process for shoulder injury.

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Conflict of interest

None.

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