Three-dimensional motion of shoulder complex during front crawl swimming

Tanghuizi Du[1] and Toshimasa Yanai[2]

Graduate School of Sport Sciences, Waseda University, Tokorozawa, Japan[1]
Faculty of Sport Sciences, Waseda University, Tokorozawa, Japan [2]

The purposes of the study were to describe glenohumeral joint motion during front crawl swimming and to determine if the glenohumeral joint motion could be predicted by the humero-thoracic motion using linear regression model. Fourteen swimmers were asked to perform a resisted front crawl swimming. Three-dimensional motions of shoulder complex were measured with an electromagnetic tracking devise. The results showed that humerus and scapula did not move in a set ratio during front crawl swimming and the glenohumeral joint motion could not be predicted accurately from the humero-thoracic motion. A characteristic movement pattern was observed in the catch phase in which the humerus moved caudally behind the scapular plane while moving in front of the torso. This movement pattern may facilitate internal rotation of the shoulder to execute the catch and pull vigorously.

KEY WORDS: glenohumeral joint, scapular motion, linear regression

INTRODUCTION: Shoulder is a complex structure. It consists of humerus, scapula, clavicle and surrounding tissues. Apparent shoulder motion represents humero-thoracic motion, although it is comprised of the humeral motion relative to scapula (i.e. glenohumeral joint motion) and the scapular motion relative to thorax (i.e. scapula-thoracic motion). The combination of the glenohumeral and scapulo-thoracic motions make shoulder the most dynamic and mobile joint in the body. In overhead sports performances, glenohumeral joint motion has important functions as the main contributor to the entire shoulder motion. Improper positioning and excessive angulation of humerus relative to scapula may cause abnormal stress to the surrounding structures and lead to shoulder injuries. Apparently, such abnormal glenohumeral motions are observed quite frequently in sports performances (Hawkins & Kennedy, 1980). A careful observation and detailed analysis of glenohumeral joint motions, therefore, is necessary for evaluating sport techniques and the risk of shoulder injuries. However, since the scapulae are covered by muscles and skin, it is difficult to visually observe glenohumeral joint motion, especially during sports activities. Due to this difficulty, details of glenohumeral joint motion in sports activities have not been described well.

In swimming, shoulders move through a large range for every stroke cycle and are susceptible to overuse injuries (Wolf, Ebinger, Lawler, & Britton, 2009). Evaluating swimmers' glenohumeral joint motion could provide coaches and trainers with valuable information for improving performance and preventing shoulder injuries. Generally, humerus and scapula are known to move in a set ratio (i.e. scapulohumeral rhythm) during normal arm elevation (Inman & Abbott, 1996). The glenohumeral joint motion may, therefore, be predicted accurately from humero-thoracic motion during simple arm abduction. However, no evidence has been shown to support that the glenohumeral joint motion could be predicted accurately from humero-thoracic motion during a complicated arm stroke of swimming. The purposes of the study, therefore, were to describe the glenohumeral joint motion during front crawl swimming and to determine if the glenohumeral joint motion could be predicted by the humero-thoracic motion using linear regression model.

METHOD: Fourteen members of a men's collegiate swim team participated in this study (body height: 1.74 ± 0.04 m; body mass: 68.6 ± 4 kg; age: 20 ± 1.2 yr; training career: 14 ± 3.1 yr). A simplified kinematic model consisting of the right scapula, right humerus, and thorax was used to describe the configurations of the right shoulder complex. An electromagnetic tracking device (LIBERTY, Polhemus, Colchester, VT) was used to record the movements of the three segments at 240 Hz. Three sensors, professionally waterproofed (STELLA Precision Co. Ltd., Ushiku, Japan), were attached to the skin over the sternum, the flat area of the right acromion, and a plastic cuff wrapped around the right humerus. The movements of thorax, right scapula and right humerus were determined as the positions and orientations of the segments with respect to the transmitter.

After a routine warm-up, each subject was asked to perform front crawl with their maximal effort. Since the electromagnetic tracking device required data collection within the magnetic field generated by the transmitter, each subject was restrained by a rubber tube to swim nearby the transmitter. The subject was asked to swim 13 stroke cycles, and the 5th and 6th stroke cycles were used for analysis. Three sequential Euler angles were used to describe the glenohumeral configuration, representing glenohumeral horizontal adduction, elevation, and internal rotation. Similarly, three sequential Euler angles were used to describe the humero-thoracic configuration, representing shoulder horizontal adduction, elevation, and internal rotation.

The means and standard deviations across the subjects for the humero-thoracic and glenohumeral joint configurations recorded during the analyzed stroke cycles were calculated. A linear regression model was used to determine if the humero-thoracic joint configuration can predict the glenohumeral joint configurations during front crawl for each subject.

RESULT: The kinematics of humero-thoracic joint and glenohumeral joint is summarized in Figure 1 and Table 1. The humero-thoracic and glenohumeral elevation angles attained the peak value at the beginning of the pull phase. With the arm moving caudally, the internal rotation angle of the two joints increased, indicating that the arm rotated internally to catch and pull the water. The horizontal abduction angle of humero-thoracic joint decreased and then increased during the pull phase, which enabled the hand to move outwards and then inwards as an “S” shape. The humero-thoracic and glenohumeral elevation angles reduced to near 0º in the upsweep phase. For recovery, the arm moved cranially while rotating externally.

During the catch phase in which the arm was rotated internally, the glenohumeral horizontal abduction angle was much smaller than 0° although the corresponding horizontal abduction angle of humero-thoracic joint maintained positive values. This difference indicates that the humerus moved caudally behind the scapular plane while moving in front of the torso. This movement pattern was observed in all subjects.

A linear regression model was established to predict glenohumeral joint motion from humero-thoracic motion during front crawl swimming (p<0.05). The humero-thoracic motion accounted for 49.3% of the variability in glenohumeral horizontal abduction, 97.3% in the glenohumeral elevation and 43.2% in glenohumeral internal rotation (Table 2). The root-mean-square error of using humero-thoracic motion to predict glenohumeral joint motion with a linear regression model was about 20º for horizontal abduction, 5º for elevation and 21º for internal rotation.

Table 1: The peak values for humero-thoracic and glenohumeral joint motion during front crawl

	Horizontal abduction		Elevation	Internal rotation	
	Maximum	Minimum		Maximum	Minimum
Humero-thoracic joint	86 ± 14º	-21 ± 13º	154 ± 5º	48 ± 11º	-37 ± 15º
Glenohumeral joint	62 ± 36º	-60 ± 32º	104 ± 9º	62 ± 41º	-62 ± 24º

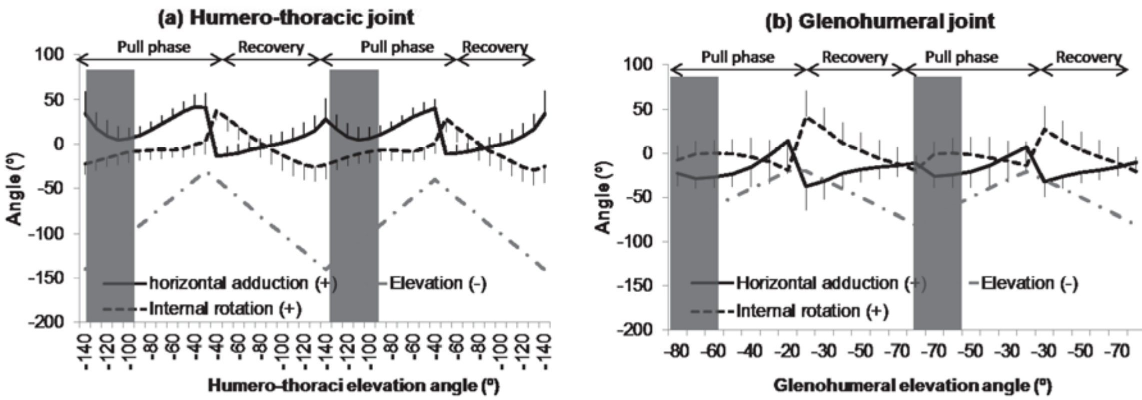

Figure 1: The means and standard deviations of horizontal abduction and internal rotation angle across the subjects for every 10° elevation in (a) humero-thoracic and (b) glenohumeral joint. The gray zones indicate the catch phase in which the humerus moved caudally behind the scapular plane while moving in front of the torso.

Table 2: Linear regression model for predicting glenohumeral joint motion with humero-thoracic motion during front crawl swimming

	Horizontal abduction	Elevation	Internal rotation
Coefficient	0.670 ± 0.301	0.755 ± 0.068	0.904 ± 0.526
Constant	-23.112 ± 14.727	12.745 ± 4.081	-4.480 ± 17.882
R^2	0.493 ± 0.277	0.973 ± 0.019	0.432 ± 0.276
Mean square of residual	495 ± 453°	31 ± 31°	477 ± 297°

DISCUSSION: Kinematic analysis of the shoulder motions demonstrated that glenohumeral motion in the catch phase was substantially different from the corresponding humero-thoracic motion. Glenohumeral joint elevation angle was found to be predicted accurately by the humero-thoracic elevation angle during resisted swimming whereas glenohumeral horizontal abduction angle and internal rotation angles were not.

The large error in predicting glenohumeral horizontal abduction angle and internal rotation angle may be partially due to the gimbal lock since the humero-thoracic and glenohumeral joint angles were described with Euler angles. When the second rotation angle is 0° or ±180°, the first and third rotation axes coincide and a mathematical indetermination occurs on the first and third rotation angle as a consequence. Although the second angle (elevation angle) rarely attained the exact angle of 0° or ±180° during front crawl swimming, it approached 0° in upward pull phase and 180° in catch phase. In these phases the measurement error in the determined Euler angles was amplified and the first and third rotation angles (horizontal abduction and internal rotation angles) were expected to be inaccurate. Van der Helm (2002) reported that such amplified errors in determining the first and third angles were evident when the second angle was in the range of ± 20° around 0° or 180°. During the swimming measurement, the humero-thoracic joint was elevated from 19 ± 6° to 154 ± 5° and glenohumeral joint was elevated from 7 ± 5° to 104 ± 9°. The determined values of the horizontal abduction and internal rotation angles, therefore, may not be reliable for some subjects when the arm was largely elevated at or around at the beginning of pull phase and/or lowered besides body at or around the end of upsweep phase.

The prediction error in glenohumeral horizontal abduction and internal rotation angles were large even in the pull phase and/or the middle of the recovery phase in which the second rotation angle was not close to 0° or 180°. These results indicate clearly that humerus and scapula do not move in a set ratio during front crawl swimming and the glenohumeral joint motion cannot be predicted accurately from the corresponding humero-thoracic motion. In other words, the patterns of change in humero-thoracic joint angles do not represent the corresponding pattern of change in glenohumeral joint angles during front crawl swimming. A vigorous arm internal rotation to catch the water and a whip-like movement of the recovery arm may result in a unique movement pattern of the scapula. Previous studies reported that scapulohumeral rhythm was altered when a load/force was applied to the arm and/or when the speed of arm motion was changed (de Groot, Valstar, & Arwert, 1998; Pascoal, van der Helm, Correia, & Carita, 2000). The forces acted on the arm and the speed of arm motion change every moment during swimming and, hence, the movement pattern of glenohumeral joint may be altered to a pattern unique to front crawl swimming. Our observations suggest, therefore, that a careful measurement and detailed analysis of glenohumeral joint motions are recommended for evaluating sport techniques and the risk of shoulder injuries.

The characteristic movement pattern was observed in the catch phase in which the humerus moved caudally behind the scapular plane while moving in front of the torso. This pattern of movement may be resulted from the arm internal rotation executed vigorously to catch water. We have observed consistently across many healthy adults that vigorous internal rotation of a humero-thoracic joint is accompanied by scapular protraction. For a given humero-thoracic joint position, an increase in the scapular protraction angle reduces the corresponding glenohumeral horizontal adduction angle, which increases the length of the internal rotator muscle to optimize the force-length relationship for the intended shoulder motion. During swimming, swimmers need to catch and pull the water effectively to accelerate body forward. We believe, therefore, that the swimmers mutually underwent the characteristic movement pattern to execute the catch and pull vigorously with the shoulder internal rotation.

CONCLUSION: During resisted front crawl swimming, humerus and scapula did not move in a set ratio during front crawl swimming and the glenohumeral joint motion could not be predicted accurately from the humero-thoracic motion. A characteristic movement pattern was observed in the catch phase in which the humerus moved caudally behind the scapular plane while moving in front of the torso. This movement pattern may facilitate internal rotation of the shoulder to execute the catch and pull vigorously.

REFERENCES:

de Groot, J. H., Valstar, E. R., & Arwert, H. J. (1998). Velocity effects on the scapulo-humeral rhythm. *Clin Biomech (Bristol, Avon), 13*(8), 593-602.

Hawkins, R. J., & Kennedy, J. C. (1980). Impingement syndrome in athletes. *The American Journal of Sports Medicine, 8*(3), 151-158. doi: 10.1177/036354658000800302

Inman, V. T., & Abbott, L. C. (1996). Observations of the Function of the Shoulder Joint. *Clinical orthopaedics and related research, 330*, 3-12.

Pascoal, A. G., van der Helm, F. F., Correia, P. P., & Carita, I. (2000). Effects of different arm external loads on the scapulo-humeral rhythm. *Clin Biomech (Bristol, Avon), 15*, S21-S24.

Van der Helm, F. (2002). A standardized protocol for the description of shoulder motions. *International Shoulder Group of the International Society of Biomechanics*.

Wolf, B. R., Ebinger, A. E., Lawler, M. P., & Britton, C. L. (2009). Injury patterns in Division I collegiate swimming. *Am J Sports Med, 37*(10), 2037-2042. doi: 10.1177/0363546509339364

Acknowledgement

This study was supported by the JSPS KAKENHI Grant Number 23300236 and Grant-in-Aid for JSPS Fellows.