DO THE TORSO MUSCLES PRODUCE TORSO TWIST IN FRONT CRAWL?

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The purpose of this study was to investigate the association between torso muscle activity and torso twist. EMG data from five torso muscles and 3D motion capture data were recorded during 4x25m front crawl swimming trials at 400m and 50m pace (N=15). EMG data were integrated over 10ms intervals and normalized to the maximum value during each swimming trial (%iEMG) and torso twist acceleration was calculated as the second time derivative of the relative angle between thorax and pelvis about the longitudinal axis. Spearman correlations were calculated between 5th percentile scores of %iEMG and torso twist acceleration. Mean correlation coefficients were weak (i.e. $r < 0.30$) for all muscles at both paces. The findings suggest that torso muscle activity may not be directly associated with torso twist acceleration.

KEYWORDS: swimming, electromyography, three-dimensional motion capture, kinematics.

INTRODUCTION: The body's rotation about the longitudinal axis in front crawl improves propulsion generation from the arms (Kudo, Sakurai, Miwa, & Matsuda, 2017) and reduces the risk of shoulder injury (Yanai & Hay, 2000). Swimmers are likely to benefit from improving their ability to control rotation between the upper and lower trunk. This may be why dry-land training exercises for swimmers tend to involve twisting movements of the trunk. However, it is unclear whether swimmers use their torso muscles to generate torso twist in front crawl, giving reason to question the specificity of exercises that involve active trunk twisting from the torso muscles. The acceleration of the thorax with respect to the pelvis depends on resolution of the equation of angular motion $\alpha = \Sigma T/I$ where T is torque acting on the thorax and I is the moment of inertia of the upper body including the thorax, head, and upper limbs. The torques acting on the thorax comprise the torque produced by the forces due to the actions of the arms, the buoyancy and gravitational forces, and the actions of the torso muscles. The angular motion of the pelvis depends on the torques due to the actions of the lower limbs, the buoyancy and gravitational forces, and the reactions to the actions of the torso muscles. Although the contributions of the forces to torque are not readily obtainable in swimming, knowledge of the relationship between torso muscle activity and rotational acceleration of the thorax with respect to the pelvis, or 'torso twist acceleration', may provide insights into the roles of the torso muscles in producing torso twist or in stabilizing the torso. Therefore, the purpose of this study was to investigate the association between torso muscle activity and torso twist.

METHODS: Fifteen male competitive swimmers (age: 20.4 ± 4.8 years; height: 177.6 ± 8.8 cm; mass: 69.6 ± 11.0 kg) were recruited for this study. Data collection was conducted in an indoor 25m pool. Participants completed a standardized 1000m warm up before being fitted with EMG apparatus and motion capture markers.
Ag-AgCl surface electrodes were adhered to the skin over internal oblique, external oblique, rectus abdominis, lumbar erector spinae, and thoracic erector spinae on the right side (Cram, Kasman, & Holtz, 1998). A reference electrode was placed on the right posterior superior iliac spine. Electrodes and EMG leads were covered with waterproof adhesive (Opsite Flexfix, Smith & Nephew Inc.). EMG data were sampled (BIOPAC Systems, Inc.) at 2000 Hz with a 16-bit A-to-D conversion and amplified (gain = 1100) with a common mode rejection ratio of 110 dB. Preamplifiers were enclosed in epoxy resin for waterproofing. Participants wore a full-body Speedo FASTSKIN™ swimsuit to help secure the EMG apparatus.
Participants' motions were captured at 100 Hz with Qualisys (Göteborg, Sweden) using 11 above water and six underwater cameras. The calibration volume (1.7 m width, 6.4 m length, 1.4 m height) was located 10m from the start wall. Reflective markers were placed over the

left and right acromion and lateral aspect of the 10th rib at the mid-axillary line and a T-shaped rigid body (80mm x 100mm) with three reflective markers was placed over the sternum to track the thorax motion. Reflective markers were adhered over the left and right superior iliac crest, anterior superior iliac spine, and greater trochanter to define and track the pelvis motion.

Participants entered the pool and swam to the calibrated volume to stand on a platform and a calibration trial of the participant standing in the anatomical position was captured before participants returned to the start wall. The testing protocol comprised 4x25m front crawl at a pace equivalent to the participant's 400m race pace. Swimmers rested in the water for 5min before completing 4x25m trials at sprint pace. Each trial began from a push start and participants were required to not breathe as they entered the calibration volume (marked on the bottom of the pool) to avoid effects of breathing on swimming technique (Psycharakis & McCabe, 2011).

Three-dimensional marker data were filtered using a 4th order low pass Butterworth filter with a 6 Hz cut-off. Thorax and pelvis angular displacements about the global horizontal axis in the swimming direction were calculated. Torso twist angle was the difference between thorax and pelvis angular displacements. Positive and negative values represent counter-clockwise and clockwise rotation, respectively, when viewing the swimmer head-on. Torso twist acceleration was the second time derivative of torso twist angle. One cycle of thorax rotation, defined from peak counter-clockwise thorax rotation to the subsequent peak counter-clockwise thorax rotation, was selected from each trial. Swimming velocity was calculated by dividing thorax horizontal displacement by the time to complete one thorax rotation cycle (m/s). Due to marker occlusion during data collection, the thorax and pelvis could not be reconstructed for the duration of one complete thoracic cycle for some trials. These trials were omitted from analysis. Across all participants, 33 trials at 400m pace and 21 trials at sprint pace contained thorax and pelvis data for every frame of one complete thorax rotation cycle and were used for analysis.

Raw EMG data were band pass filtered (4th order Butterworth, 20 to 500 Hz). The mean was subtracted from the filtered EMG and a full-wave rectifier was applied. Full-wave rectified EMG was integrated over 10ms intervals of the thoracic cycle to match the sampling frequency of the motion capture data (i.e. 100 Hz). Integrated EMG and torso twist acceleration were standardized to 201 points of the thoracic cycle using Fourier transform and inverse transform (Sanders, Gonjo, & McCabe, 2015) such that each datum represented a half percentile (i.e. 0-100%). Integrated EMG data were then divided by the maximum value from each trial to produce a percentage of maximum muscle activity (%iEMG) for each percentile of the thorax rotation cycle. Ensemble averages and 95% confidence intervals (95%CI) of the true mean were calculated for torso twist acceleration and %iEMG for each percentile of the thorax rotation cycle at both paces. Confidence intervals were calculated as the *z*-score (determined using the *t*-distribution of the sample size) multiplied by the standard error of the sample mean. Percent iEMG and torso twist acceleration were averaged for every 5^{th} percentile of the thorax rotation cycle, producing twenty scores for %iEMG and torso twist acceleration over the entire cycle for each trial. %iEMG data were not normally distributed. Therefore, Spearman Rank-Order correlation tests were used to correlate 5^{th} percentile %iEMG scores with 5^{th} percentile torso twist acceleration scores over the entire thorax rotation cycle. Five separate tests (one for each muscle) were conducted for each trial at both paces to explore the relationships between %iEMG and torso twist acceleration. The mean and range of the correlation coefficients across participants were analysed and interpreted using Cohen's (1988) recommendations (weak: $r < 0.30$; moderate: $r = 0.30$ to 0.50 strong: $r > 0.50$).

RESULTS: Average swimming velocity was 1.4 ± 0.1 m/s and 1.6 ± 0.1 m/s at 400m and sprint pace, respectively. There were two peaks in internal oblique activity at both paces: one between 20 to 40% and one between 50 to 70% of the thoracic cycle (Figure 1). During these parts of the cycle, torso twist acceleration acted in both the clockwise and counter-clockwise directions with no obvious pattern with respect to the changes in internal oblique activity. Similarly, the increases in external oblique activity at the beginning of the cycle at both paces and at 80% of the cycle at sprint pace did not seem to relate to changes in torso twist acceleration. There were no clear patterns between torso twist acceleration and the changes of rectus abdominis, lumbar erector spinae, or thoracic erector spinae activity at either pace. Mean correlation coefficients for the relationships between %iEMG and torso twist acceleration were weak for all muscles at both paces. The range of coefficient values from individual participants was large for every correlation (Table 1).

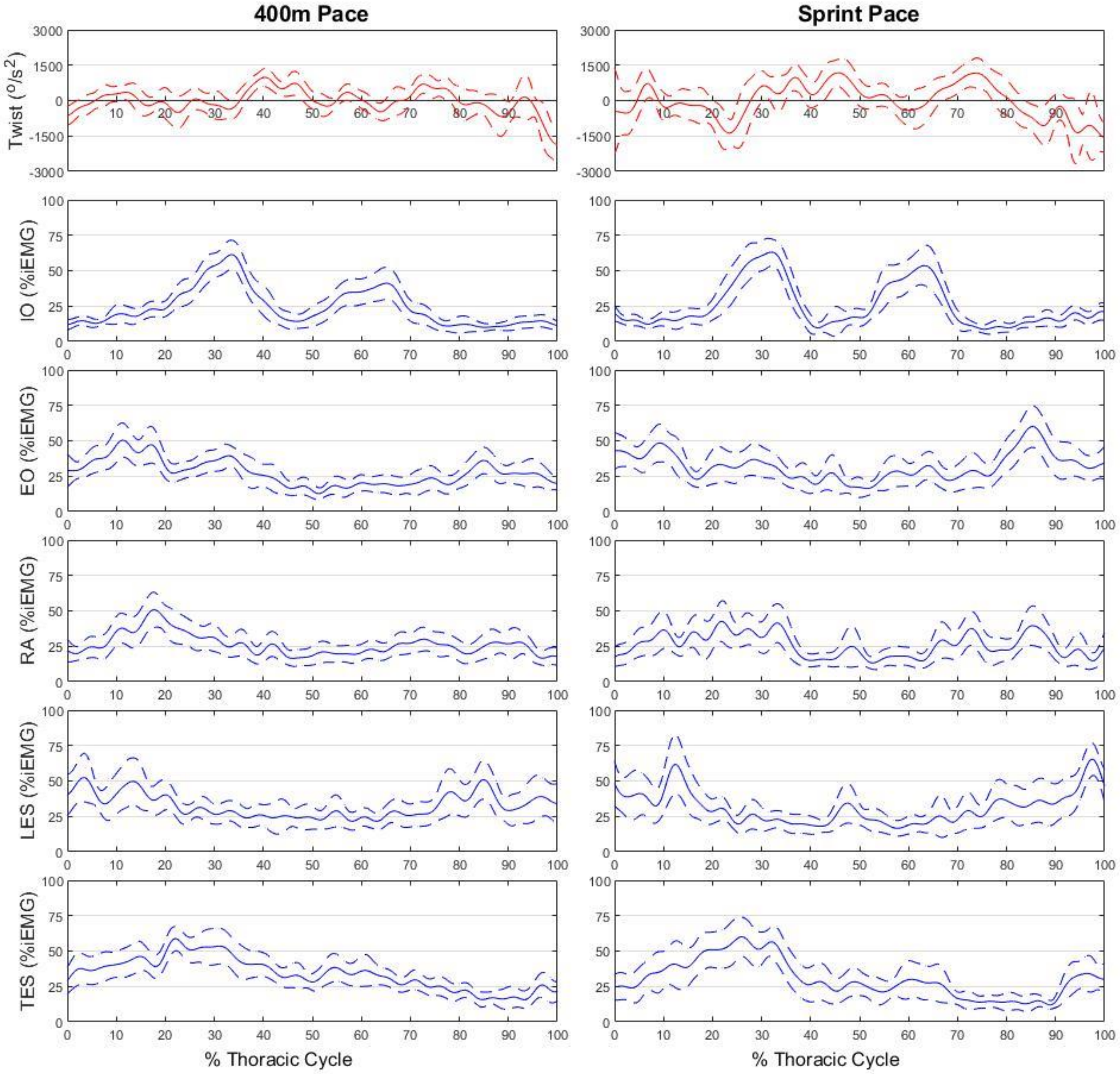

Figure 1. Time series graphs of ensemble averages (solid lines) with 95%CI of the true mean (dashed lines) for torso twist acceleration (top) and %iEMG (bottom five) at 400m (left) and sprint pace (right).
IO = internal oblique, EO = external oblique, RA = rectus abdominis, LES = lumbar erector spinae, TES = thoracic erector spinae.

Table 1. Mean (range) of Spearman correlation coefficients (*r*) between torso muscle %iEMG and torso twist acceleration at 400m pace and sprint pace.

	Internal Oblique	External Oblique	Rectus Abdominis	Lumbar Erector Spinae	Thoracic Erector Spinae
400m Pace	-0.09 (-0.54 to 0.34)	-0.05 (-0.34 to 0.26)	-0.05 (-0.53 to 0.56)	-0.13 (-0.63 to 0.30)	-0.03 (-0.39 to 0.35)
Sprint Pace	-0.07 (-0.34 to 0.37)	-0.18 (-0.61 to 0.29)	-0.03 (-0.32 to 0.39)	-0.11 (-0.40 to 0.31)	-0.15 (-0.51 to 0.17)

DISCUSSION: This is the first study in the existent literature about the relationship between torso muscle activity and torso twist in front crawl swimming. The findings presented here help develop our understanding of the roles the torso muscles may (or may not) play in front crawl performance and have implications for training.

Torso twist acceleration did not display a direct relationship to muscle activity at either pace, suggesting that the torques that produce torso twist are mainly from sources other than the torso muscles, for example, possibly from the actions of the arms and legs. Rather than generating rotation between the upper and lower torso, swimmers may use the torso muscles to stabilize the spine. This could help control the effects of external torques generated by the arm stroke and flutter kick so that rotation about the longitudinal axis is optimal for performance. Further, the torso muscles provide spine stability for generating forces that *produce* limb movements (Hodges, Cresswell, Daggfeldt, & Thorstensson, 2000; Hodges & Richardson, 1997). The spine stability provided by the torso muscles may enhance the effectiveness of the arm stroke and flutter kick by creating a platform from which hydrodynamic reaction forces can be generated for forward propulsion.

Considering the importance of the torso muscles for spine stability during axial trunk rotation (Marras & Granata, 1995), there is also a possibility that swimmers use the torso muscles to help maintain trunk posture in front crawl as one of their main roles. Rotation about the longitudinal axis is also influenced by the side to which a swimmer prefers to breathe, even when they do not take a breath during a stroke cycle (Psycharakis & McCabe, 2011). The association between torso muscle activity, posture, and preferred breathing side should be investigated to further improve our understanding of the torso muscle roles in front crawl.

CONCLUSION: Torso muscle activity is not directly associated with torso twist acceleration in 400m and 50m front crawl swimming. The torso muscles may be more important for optimizing longitudinal body rotation, producing spine stability to assist the limbs in generating motion, and maintaining trunk posture. Further research is required to investigate these potential roles of the torso muscles. Exercises that require swimmers to generate axial spine rotation with the torso muscles may not necessarily improve the specificity of dry-land training for front crawl. Training may be better directed towards strengthening the torso muscles to improve their function in maintaining posture and stability to optimize performance.

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