KNEE AND ANKLE MUSCLES COACTIVATIONS IN BREASTSTROKE SWIMMING KICK AND RECOVERY: EXPLORATORY APPROACH

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The specificities of body position in breaststroke induce important lower limbs solicitations for the swimmers to propel themselves efficiently. Coactivations around the knee and ankle might appear during the powerful leg extension (i.e. push) and for leg replacement (i.e. recovery). The purpose of this exploratory study is to determine muscle activations and coactivations during these two phases at three different velocities. The EMG of four muscles was recorded (BF, RF, GAS and TA). The results showed important activations of the four muscles in the push, contrary to the recovery. However, no significant differences were found for the coactivations in the two phases and for the three velocities. These findings denoted the important resistances occasioned by aquatic environment, both in push and recovery phases, necessitating muscle coactivations to stabilise joints.

KEY WORDS: swimming, breaststroke, co-contractions, EMG, flexion-extension, kick.

INTRODUCTION: Among the four swimming styles, breaststroke presents the highest velocity fluctuations during one stroke cycle (Chollet, Seifert, Leblanc, Boulesteix, & Carter, 2004). This is mainly due to the atypical oblique angle adopted by the swimmers to progress forward. To overpass these constraints, a powerful extension is necessary to accelerate strongly the body (gain of 1 to 1.5 m s^{-1} for each breaststroke kick according to Takagi, Sugimoto, Nishijima, & Wilson, (2004)). Therefore, the push is a determinant phase in this aquatic movement and must be performed in an appropriate way from a kinematical and muscular point of view. To a lesser extent, the recovery is likewise crucial since this phase positioned the lower limbs segments for a new kick.
Muscular solicitations must be consequent during these phases according to the important execution speed and the aquatic resistances, to stabilise the joints and to position efficiently the propulsive areas (i.e. mainly the feet). The notion of coactivation is generally mentioned to characterise these specifics sequences of movement. Coactivations are involved for the movement efficiency and safety (Remaud, Guével, & Cornu, 2007), and likewise to control the velocity and the precision of motion (Cappellini, Ivanenko, Poppele, & Lacquaniti, 2006). Despite the determinant role of the lower limbs stabilisation in breaststroke, no study focused on the coactivations in this locomotion (Martens, Figueiredo, & Daly, 2014). Lauer, Figueiredo, Vilas-Boas, Fernandes, & Rouard (2013) and Caty et al. (2007) determined muscle coactivations at the elbow and wrist level in front crawl swimming. It appeared that the coactivations were phase dependent (for instance highest levels observed during the aquatic elbow flexion and the aerial elbow extension) to overpass the drag and to position properly the limbs before the hand entry. At the sight of these results, there is an interest to study coactivations in swimming motion, due to the constraining aquatic environment. The purpose of this study is twofold: (i) assess for the first time in breaststroke knee and ankle muscles coactivations during the two motor phases of the kick (i.e. push and recovery) and (ii) evaluate the impact of a velocity increase on these coactivations. We hypothesised that muscle activations would be greater during the push compared to the recovery and that the level of coactivations would increase with the velocity elevation.

METHODS: Participants and testing procedure: One international- and two national-level female breaststrokers volunteered for this study (19.7 ± 7.4 years; 1.68 ± 0.04 m; 67 ± 5.5

kg). They were informed about the procedure and signed a consent approved by the local ethics committee. After a standard warm-up, the swimmers performed three 25-m bouts at 60%, 80% and 100% of their best performance on a 100-m breaststroke event. Sufficient rest of 3 minutes was accorded to the swimmers between each set of 25-m, to avoid fatigue appearance, which as negative impact on coactivations (Kellis, Zafeiridis, & Amiridis, 2011).
Data collection: The kinematic of the lower limbs was measured using the motion capture technique at a frequency of 100 Hz (Qualisys Track Manager 2.6, Qualisys, Gothenburg, Sweden). Six reflective markers were fixed on the right side of the body (trochanter major, lateral femoral condyle, medial and lateral malleolus, first and fifth metatarsals).
The electrical activity of two antagonist pairs of muscles of the lower limb was recorded according to ISEK electrodes placement recommendations (Merletti, Botter, Troiano, Merlo, & Minetto, 2009). Two muscles around the knee (rectus femoris (RF) and biceps femoris (BF)) and around the ankle (medial head of M. gastrocnemius (GAS) and tibialis anterior (TA)) were chosen according to their main contribution in the breaststroke kick (Yoshizawa, Okamoto, Kumamoto, Tokuyama, & Oka, 1978). The signals were recorded at a sampling frequency of 1000 Hz. The electrodes (20 mm inter-electrodes distance) were waterproofed and connected to a pre-amplifier (band-pass filter of 8–500 Hz, input impedance>100 MΩ, common mode rejection ratio 110 dB and gain 1000). An electronic flashlight signal was marked simultaneously on the video and EMG recordings to synchronize it.
Data treatment: Knee and ankle angles were computed in the sagittal plane to discriminate the breaststroke kick phases. We determined three main phases by adapting the work of Chollet et al. (2004): the push (corresponding to leg propulsion and insweep in their study), the glide and the recovery. We studied coactivations on the active phases of the breaststroke kick (i.e. push and recovery). The push starts with a backward movement of the feet (leg extension) and ends when the feet are joined together, with lower limbs fully extended. The recovery is characterized by a knee and ankle flexion, with a forward movement of the feet.
MATLAB 2014a software (MathWorks Inc., Natick, MA, USA) was used for signal EMG processing. Raw EMG signals were filtered using a fourth-order Butterworth band-pass filter (bandwidth 8–500 Hz) and a high pass filter (cut-off frequency of 20 Hz), rectified and averaged to obtain the full wave signals. The integration of the rectified EMG was calculated per unit of time for each phase to eliminate the effect of phase duration (iEMG/T). Signals were partitioned in 40 ms windows to find the maximal iEMG (iEMGmax) for the four studied muscles. iEMG/T was expressed as a percentage of iEMGmax to normalize the results (Burden, 2010). Normalized iEMG/T (%) were then calculated per phase for the four studied muscles (RFiEMG, BFiEMG, GASiEMG and TAiEMG). Finally, muscle coactivations were computed using the adapted Coactivation Index (CI) formula of Kellis et al. (2011):

$$CI = \frac{iEMG_{anta}}{(iEMG_{anta} + iEMG_{ago})} \times 100$$

where $iEMG_{anta}$ and $iEMG_{ago}$ respectively refers to iEMG of antagonist and agonist muscle in a given phase. Accordingly, during the push —decomposed in a knee extension and a plantar flexion of the foot— the RF is considered as agonist and the BF antagonist (proximal level), and the GAS agonist and the TA antagonist (distal level). In the recovery phase, the function of each muscle is inverted. Non-parametric Friedman two ways ANOVA on ranks were performed to evaluate the effects of velocities and type of phases on the muscular activations and coactivations (with Wilcoxon matched-pairs signed-ranks tests in post-hoc).

RESULTS: The phases durations were 26.3 ± 4.2%, 41.0 ± 1.0% and 32.7 ± 4.9% of the total stroke duration for push, glide and recovery, respectively. The duration of each stroke cycle was sensitive to swimming velocity: 1.79 ± 0.15 s for 60%, 1.44 ± 0.12 for 80% and 1.37 ± 0.10 for 100%. The knee angles variations ranged from 36.5 ± 12.9 deg at the beginning of the push to 157.4 ± 11.5 deg when the lower limbs are fully extended for the three subjects and the three tested velocities. This angle was maintained during the glide before the knee flexion corresponding to the recovery phase. Important knee angular velocity was observed during the push (i.e. 548 ± 46 deg s^{-1}), corresponding to a powerful extension.

The ankle angle was 97.2 ± 15.4 deg at the start of the push and increased until 130.9 ± 14.7 deg at the end of the push. As for the knee angle, this value was maintained during the glide before a decrease to adopt the configuration of a new push phase.
iEMG for the four muscles are presented for the three velocities and among the two phases in Figure 1. Muscular activities were in average lower (no significant difference) during the recovery phase than during the push phase, for the four muscles and the three velocities ($p<0.05$). Within each phase, the effects of velocity increase do not affect uniformly the muscular solicitations (only the activation of the GAS during the push at the 80% velocity level has a strong tendency to be lower ($p=0.06$) compared to 60% and 100%).

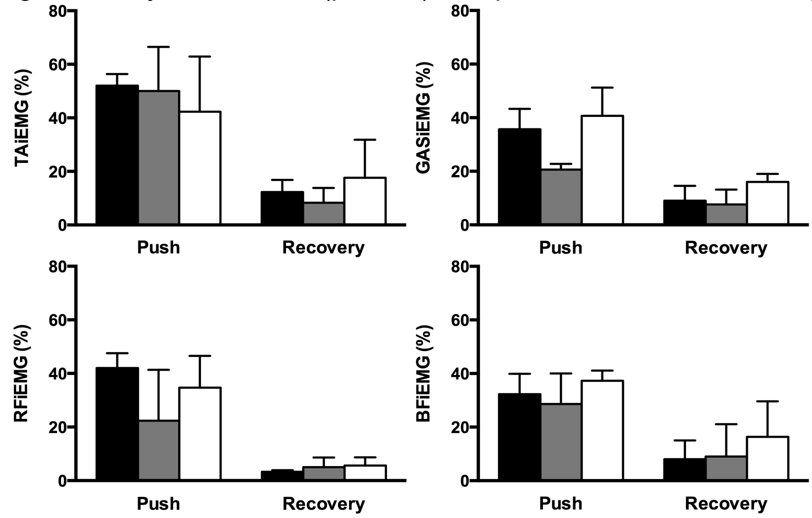

Figure 1: Average values and standard deviations for the normalised integrated EMG (%) per phase and for the three velocities (60% in black, 80% in grey and 100% in white).

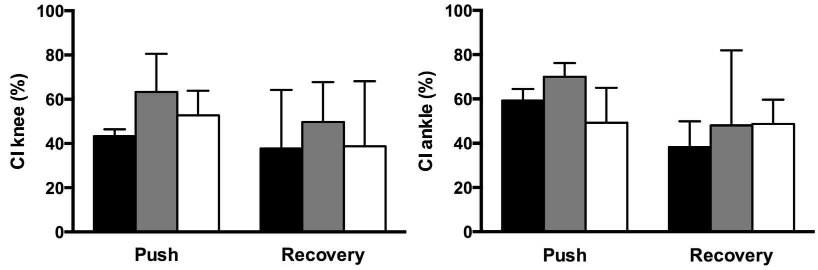

Figure 2: Average values and standard deviations for the coactivation index (CI) (%) per phase and for the three velocities (60% in black, 80% in grey and 100% in white).

The results of the CI computation are presented in Figure 2. Qualitatively, knee and ankle muscles coactivations were higher during the push than during the recovery for the three velocities. The coactivations around the knee were the lowest for the 60% velocity level, and the highest at the 80% velocity level, for the two studied phases, with no significant differences. In all situations, the CI computed for the ankle muscles were in average higher than those for the knee muscles.

DISCUSSION: The purpose of this exploratory study was to assess knee and ankle muscles coactivations during the motor phases of the breaststroke kick performed at three different velocities. The kinematics variables were consistent with previous values reported by Chollet et al. (2004). Moreover, the angular velocity observed at the knee denoted a powerful lower limbs extension during the push. This resulted in higher activations for all the studied muscles and the three velocities during this propulsive phase, in comparison to the legs replacement during the recovery. These findings were similar to those obtained in one of the earliest EMG works in breaststroke (Yoshizawa et al., 1978), with important solicitations of the muscles in the push, compared to lower discharge during the recovery. iEMG of the four studied muscles during the recovery were similar to those observed in crawl during the *ext air* phase for BB and TB, despite an aquatic limbs replacement in breaststroke (Lauer et al.,

2013). This suggested that the resistances due to the presence of water did not affect the muscular actions in breaststroke recovery phase.
The computation of CI presented no statistical differences between the two phases and the three velocities for knee and ankle muscles coactivations (likely related to the small sample size). Contrary to others swimming styles, breaststroke coactivations were not phase-dependant (Caty et al., 2007; Lauer et al., 2013). Indeed, the presence of coactivations in breaststroke is linked to (i) the necessity to perform an explosive and efficient push (coactivations played a precision and security role) and (ii) the replacement of the limbs against water resistance (active maintaining of the limbs position to limit the drag increase). Moreover, the impact of velocity is limited on the coactivations, contrary to others previous studies performed on land (Draganich, Jaeger, & Kralj, 1989). It could be related to the specificities of aquatic environment since water drag induces important joints stabilisation (in particular at the ankle level) either in propulsive or replacement phases.

CONCLUSION: This first approach to determine coactivations in breaststroke swimming showed in average no statistical differences between the two analysed phases, contrary to apparent greater muscles solicitations in the push. Moreover, there was no impact of the swimming velocity for knee and ankle muscles coactivations. These results, obtained on a small sample size, provide the importance of having an appropriate muscular balance to stabilise joints when swimmers performed the breaststroke kick. Such findings might be used by coaches to adapt musculation exercises during the training.

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