International Journal of Aquatic Research and Education

5-1-2010

Muscle Activity During the Typical Water Polo Eggbeater Kick

Nuno Oliveira
University of Porto, Faculty of Sport, noliveira@kesslerfoundation.org

Ricardo Jorge Fernandes
University of Porto, Faculty of Sport

Mariana Sarmento
University of Porto, Faculty of Sport

Silverio Liberal
University of Porto, Faculty of Sport

Pedro Alexandre Figueiredo
University of Porto, Faculty of Sport

See next page for additional authors

Follow this and additional works at: https://scholarworks.bgsu.edu/ijare

Muscle Activity During the Typical Water Polo Eggbeater Kick

Authors

Nuno Oliveira, Ricardo Jorge Fernandes, Mariana Sarmento, Silverio Liberal, Pedro Alexandre Figueiredo, Pedro Gonçalves, and João Paulo Vilas-Boas

Muscle Activity During the Typical Water Polo Eggbeater Kick

Nuno Oliveira, Ricardo Jorge Fernandes, Mariana Sarmento, Silvério Liberal, Pedro Alexandre Figueiredo, Pedro Gonçalves, and João Paulo Villas-Boas

The muscle activity of the *Tibialis Anterior*, *Gastrocnemius Medialis*, *Adductor Longus*, *Vastus Medialis*, *Tensor Fasciae Latae*, and *Bíceps Femoris* muscles in the typical water polo eggbeater kick were evaluated for four national level water polo players. The surface electromyographic (EMG) signals were collected during an intermittent protocol in which the basic position with arms up and horizontal position variations were performed. Descriptive and inferential statistics (including ANOVA) were calculated using the $p < .05$ significance level. We observed that different muscles have different relevance during the eggbeater kick cycle, changing as a function of the movement phase. When comparing the three variations of eggbeater kicks, differences were noticed within each phase: the outward phase and the power phase seem to impose higher muscular activity than the recovery phase for most of the muscles studied. Considering the eggbeater kick variations, arms up seems to produce higher EMG values, while the basic position and the horizontal position seem to create similar EMG values.

The eggbeater kick is a basic and commonly used water polo technique, being similar to the breaststroke kick, with the exception that the limbs move alternately instead of moving symmetrically together (Clarys, 1975). It allows the player to raise (and sustain) the body out of the water or move it in any desired direction by generating a force to counteract the gravitational pull on body weight or any other resistance (e.g., the opponent player or simply the water drag force). Consisting of cyclic actions, this specific technique implies that the right and left lower limbs move in a circular trajectory in opposite directions and out of phase, which means that while one limb is executing its power phase (extension), the other is making the opposite recovery phase action (Sanders, 1999a), allowing a continuous propulsion. The eggbeater kick is a complex combination of hip, knee, and ankle motions, which demands coordination and different levels of muscle activation. Following Sanders (1999b), its distinct cycle phases are characterized by the different foot directions: (a) the outward phase, when the foot (with the flexed knee) starts rotating laterally and moving outward (Figure 1, left panel); (b) the power phase, the most propulsive one (Sanders, 2005), starts after the outward phase when the foot begins its movement downward and inward (Figure 1, central panel); and (c) the

---

The authors are with the Cifi²d from the Faculty of Sport at the University of Porto in Porto Portugal.
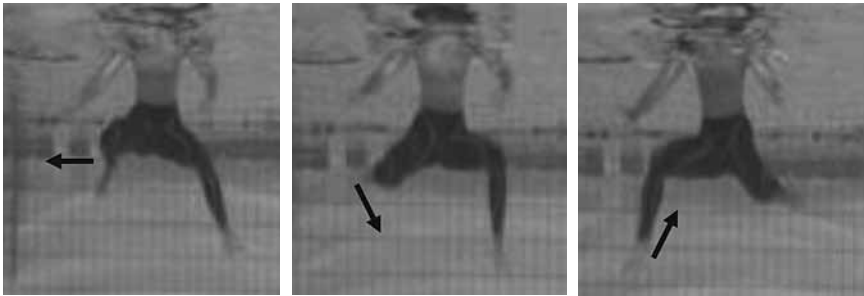
Figure 1 — Different phases of the eggbeater kick: outward, power phase, and recovery phase, respectively, in the left, central, and right panel.

recovery phase that occurs when the foot moves upward, resulting from flexion of the knee (Figure 1, right panel). According to Sanders (2005), the propulsion and the height that the water polo player can maintain through the execution of the eggbeater kick is determined by the ability to generate high foot velocities, which can be related to the muscular function. To perfect the teaching and learning process or simply to improve performance, it is of primary importance to have a thorough knowledge of the activation pattern of the lower limb muscles during the eggbeater kick. The information required to understand this specific kick movement includes identifying the active lower limb muscles and to precisely recognize their timing and level of activation. In addition, it is important to understand which motor control strategies should be adopted in response to various constraints (e.g., intensity of the movement, fatigue, training status or body position).

Although it is not new (cf. Clarys, 1983), the use of surface underwater electromyography (EMG) continues to be difficult to operate, namely due to the limits imposed by the aquatic environment (Aleksandrovic, Naumovski, Radovanovic, Geogiev, & Popovski, 2007) as well as to an apparent lack of uniformity and standardization in some methodological aspects (Rainoldi, Cescon, Bottin, Casale, & Caruso, 2004). As the eggbeater kick is considered a fundamental skill in water polo, characterized by complex trajectories and totally performed underwater, it seems pertinent to study this movement, specifically to understand the activation and contribution of lower limbs musculature. The purposes of this study were to describe, compare, and analyze the contribution of the *Tibialis Anterior*, *Gastrocnemius Medialis*, *Adductor Longus*, *Vastus Medialis*, *Tensor Fasciae Latae*, and *Bíceps Femoris* muscles during three variations of the eggbeater kick action used in water polo, in the basic position, with the arms up and in a horizontal position and to relate the three different phases of the kick cycle, both within and between the kick variations.

Method

Participants

Four national level water polo players averaging 20.0 ± 2.3 years old, height of 175.1 ± 7.7 cm and body mass of 72.2 ± 8.1 kg, volunteered to participate in this study. All

participants signed a written informed consent, in which the experimental protocol was described. The local Ethics Committee approved the experimental protocol.

Testing Procedures

The test session took place in a 25 m indoor swimming pool, with the water maintained at 27.5 °C. Briefly, each participant performed an intermittent protocol of 2 × 5 s in each kind of eggbeater kick, i.e., in the basic position assumed by the player during the game, in a vertical position but with the arms up (i.e., out of water), and in the horizontal position pushing against the swimming pool wall with arms extended and shoulders out of the water. Players were advised to achieve and sustain the highest vertical body position when executing the basic and the arms up positions and to push the wall at maximum strength when assuming the horizontal position.

Data Collection

A qualitative analysis of the described patterns of the eggbeater kick was conducted through video image analysis, captured with a digital video camera (Sony GR-SX1) recording at 50 Hz in the frontal plane, from an anterior view, for the basic and the arms up positions and from a posterior view for the horizontal position. Video records were analyzed using APAS software (Ariel Dynamics Inc, USA). Synchronization between the video images and the EMG signal was accomplished through a light-trigger visible in the underwater video camera (Figure 2).

Active differential surface EMG recording was used to assess the electrical activity of the *Tibialis Anterior*, *Gastrocnemius Medialis*, *Adductor Longus*, *Vastus Medialis*, *Tensor Fasciae Latae*, and *Bíceps Femoris* muscles. These muscles were selected according to their main function and anatomic location. The agonistic and antagonistic actions of muscles were also taken into account for muscle selection. The *Adductor Longus* was selected based on the need for a muscle with major role in the adduction motion and that it has been identified to be an important muscle in this specific movement (Sanders, 2005).

After the skin was shaved, treated, and rubbed with an alcohol solution (as proposed by Basmagian & De Luca, 1985), Ag/AgCl circular, bipolar, and active surface electrodes (5 mm diameter) were attached to the skin with a 20-mm inter-

Figure 2 — Images obtained by the camera placed in the frontal plane with anterior view and the light-trigger switched-off (left panel), and with posterior view and the light-trigger switched-on (right panel).

electrode distance. The electrodes were placed longitudinally with respect to the underlying muscle fiber arrangement and located according to the recommendations by SENIAM (Surface EMG for Non-Invasive Assessment of Muscles; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). A reference electrode was placed on the patella. An AD621 BN preamplifier (2.5 × 1.8 cm) with a 100 gain and a 110 DB for Common Mode Rejection Ratio was used. The signal was then conditioned and amplified 11 times in a total amplification of 1100 (cf. Gonçalves et al., 2006). Electrodes were isolated using water resistant adhesive tape (cf. Hohmann, Kirsten, & Kruger, 2006; Rainoldi et al., 2004; Rouard, Billat, Deschodt, & Clarys, 1993). Afterward, the recorded signal was converted, at 16 bits resolution with a ± 10 V input voltage range, at an acquisition rate of 1000 Hz, by an analogical/digital converter (BIOPAC System, Inc).

EMG data were collected during two 5 s trials of maximal voluntary contractions, always with verbal encouragement, for each muscle being studied. The tests were performed in sitting or supine positions while manual pressure and straps were used to keep the body segments immobile (cf. Palmer & Epler, 1998). All subjects were familiarized with the test procedures before testing.

Data Treatment

Signals analysis and processing was conducted using the Acknowledge 3.2.5 software (BIOPAC System, Inc). The raw EMG data were filtered using a digital Hamming band-pass filter (35–500 Hz), full-wave rectified, smoothed using a low-pass filter of 10 Hz, and amplitudes scaled to maximum voluntary contractions.

Statistical Analysis

A repeated-measures ANOVA test was applied to observe if there were significant differences in EMG between phases and position variations of the eggbeater kick. A least significant difference pairwise multiple comparison analysis (LSD post hoc test) was performed to determine the significance of the differences between pairs of means. Statistical significance was accepted when $p < .05$.

Results

In Figures 3, 4, and 5, it is possible to observe the normalized EMG values obtained in each phase of the three positional variations of the eggbeater kick (basic position, hands up and horizontal position, respectively).

Regardless of the type of position variation of the eggbeater kick performed, the *Tibialis Anterior*, *Vastus Medialis*, *and Bíceps Femoris* muscles showed higher EMG values always in the outward phase of the movement, while the *Gastrocnemius Medialis*, *Adductor Longus* and *Tensor Fasciae Latae* muscles had the highest values during the power phase.

Tables 1, 2, and 3 present the normalized EMG values for the different phases (i.e., outward, power, and recovery phases, respectively) in each positional variation of eggbeater kick. The arms up variation always had higher significant EMG values than during the basic position variation. The same tendency was observed regarding the horizontal position variation, but the differences were not statistically significant.
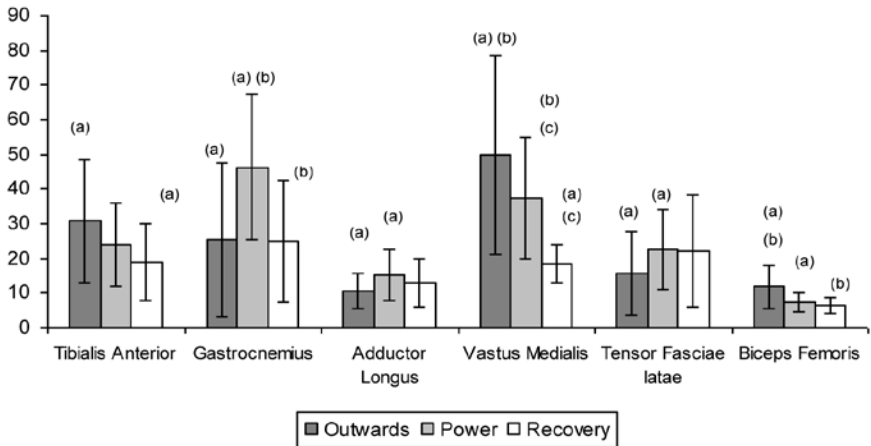
Figure 3 — Mean ± *SD* values of % MVC for the muscles *Tibialis Anterior*, *Gastrocnemius Medialis*, *Adductor Longus*, *Vastus Medialis*, *Tensor Fasciae Latae* and *Bíceps Femoris* for each phase of the eggbeater kick in the basic position. [a], [b] and [c]: significant differences between phases.

Figure 4 — Mean ± *SD* values of % MVC for the muscles *Tibialis Anterior*, *Gastrocnemius Medialis*, *Adductor Longus*, *Vastus Medialis*, *Tensor Fasciae Latae* and *Bíceps Femoris* for each phase of the eggbeater kick in the arms up. [a], [b] and [c]: significant differences between phases.

Finally, in Figures 6 and 7, we have presented some examples of the EMG patterns of the activity of the six muscles under study for one eggbeater kick cycle.

It is possible to state that the *Vastus Medialis*, the *Gastrocnemius Medialis*, the *Tensor Fasciae Latae*, and the *Biceps Femoris* muscles all showed well defined patterns of activity, during which their peak activation was very clear. In contrast, the *Tibialis Anterior* and the *Adductor Longus* muscles illustrated low patterns of activity in comparison with the other four muscles.
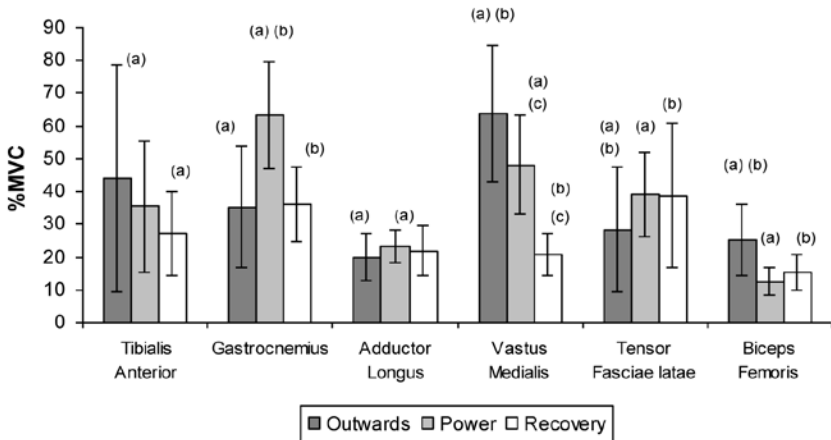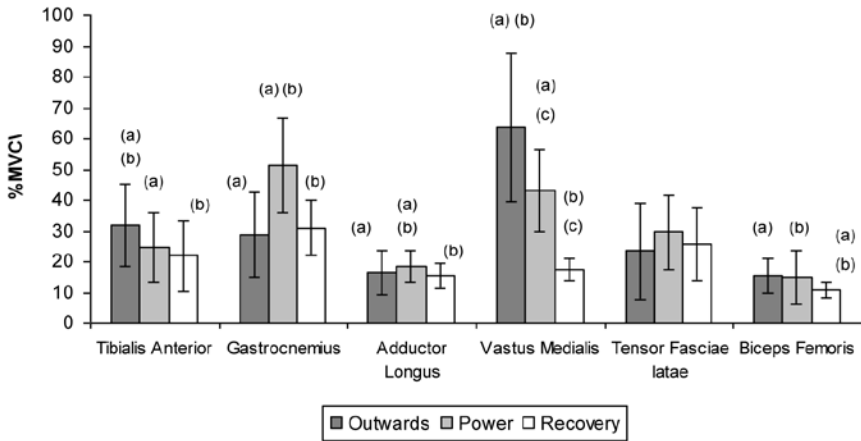
Figure 5 — Mean ± *SD* values of %MVC for the muscles *Tibialis Anterior*, *Gastrocnemius Medialis*, *Adductor Longus*, *Vastus Medialis*, *Tensor Fasciae Latae* and *Bíceps Femoris* for each phase of the eggbeater kick in the horizontal position. [a], [b] and [c]: significant differences between phases.

Table 1   Mean ± SD Values of % of Maximum Isometric Voluntary Contraction (%MVC) for the muscles *Tibialis Anterior* (TA), *Gastrocnemius Medialis* (GM), *Adductor Longus* (AL), *Vastus Medialis* (VM), *Tensor Fasciae Latae* (TFL), and *Bíceps Femoris* (BF) for the Outward Phase

	Outward Phase (%MVC)					
	TA	**GM**	**AL**	**VM**	**TFL**	**BF**
Basic Position	30.79 ± 17.81[a]	25.50 ± 22.07[a]	10.78 ± 5.10[a,b]	49.98 ± 28.68[a,b]	15.75 ± 12.13[a]	11.82 ± 6.13[a]
Arms Up	44.00 ± 34.64[a,b]	35.30 ± 18.65[a]	19.98 ± 7.37[a]	63.60 ± 20.72[a]	28.43 ± 19.08[a]	25.03 ± 10.88[a,b]
Horizontal Position	31.79 ± 13.34[b]	28.55 ± 13.85	16.51 ± 7.28[b]	63.78 ± 24.16[b]	23.34 ± 15.74	15.30 ± 5.66[b]

Note. [a], [b], and [c] show differences between variants of the eggbeater kick ($p < .05$).

Discussion

The game of water polo is played above the surface of the water, which implies that players must keep their heads out of the water leaving both upper limbs free for contacting the opponent and playing the ball whenever possible. This head-out constraint, in addition to the fact that approximately 63% of the total time during a match is spent in a vertical position (Dopsaj & Matkovic, 1994), indicates a large demand placed on the muscles of the lower limbs which in turn justifies a more

Table 2   Mean ± *SD* Values of % of Maximum Isometric Voluntary Contraction (%MVC) for the Muscles *Tibialis Anterior* (TA), *Gastrocnemius Medialis* (GM), *Adductor Longus* (AL), *Vastus Medialis* (VM), *Tensor Fasciae Latae* (TFL), and *Bíceps Femoris* (BF) for the Power Phase

	Power Phase (%MVC)					
	TA	**GM**	**AL**	**VM**	**TFL**	**BF**
Basic Position	24.04 ± 11.88[a]	46.33 ± 20.96[a]	15.29 ± 7.29[a,c]	37.29 ± 17.46[a]	22.55 ± 11.57[a,c]	7.43 ± 2.81[a,b]
Arms Up	35.52 ± 19.98[a,b]	63.15 ± 16.35[a,b]	23.22 ± 5.00[a,b]	48.18 ± 15.29[a]	39.04 ± 12.87[a,b]	12.57 ± 4.40[a]
Horizontal Position	24.56 ± 11.33[b]	51.36 ± 15.53[b]	18.34 ± 5.23[b,c]	42.88 ± 13.34	29.57 ± 12.19[b,c]	14.88 ± 8.47[b]

Note. [a], [b] and [c] show differences between variants of the eggbeater kick ($p < .05$).

Table 3   Mean ± *SD* Values of % of Maximum Isometric Voluntary Contraction (%MVC) for the Muscles *Tibialis Anterior* (TA), *Gastrocnemius Medialis* (GM), *Adductor Longus* (AL), *Vastus Medialis* (VM), *Tensor Fasciae Latae* (TFL), and *Bíceps Femoris* (BF) for the Recovery Phase

	Recovery Phase (%MVC)					
	TA	**GM**	**AL**	**VM**	**TFL**	**BF**
Basic Position	19.08 ± 11.03[a]	24.73 ± 12.51[a]	12.87 ± 6.87[a]	18.33 ± 5.51	22.27 ± 10.57[a]	6.49 ± 2.41[a,c]
Arms Up	27.22 ± 12.95[a]	36.09 ± 11.06[a]	22.00 ± 7.83[a,b]	20.89 ± 6.46[a]	38.71 ± 12.87[a,b]	15.40 ± 5.49[a,b]
Horizontal Position	21.84 ± 11.36	30.92 ± 9.00	15.50 ± 4.10[b]	17.39 ± 3.51[a]	25.82 ± 11.74[b]	10.55 ± 2.56[b,c]

Note. [a], [b] and [c] show differences between variants of the eggbeater kick ($p < .05$).

detailed neuromuscular study of the eggbeater kick. The need for the current study to analyze using surface EMG the level of activation of six lower limb muscles involved in the execution of three positional variations of the eggbeater kick, as well as to compare the involvement of each of those six muscles during the three phases of the kick cycle, is justified.

Although other aquatic studies that used this EMG analysis methodology are available in the literature— cf. the EMG activity of the shoulder muscles during water polo shots (Rebocho et al., 2008), during front crawl arm recovery (Figueiredo et al., 2007) and of the lower limbs muscles during swimming flip turns (Pereira et
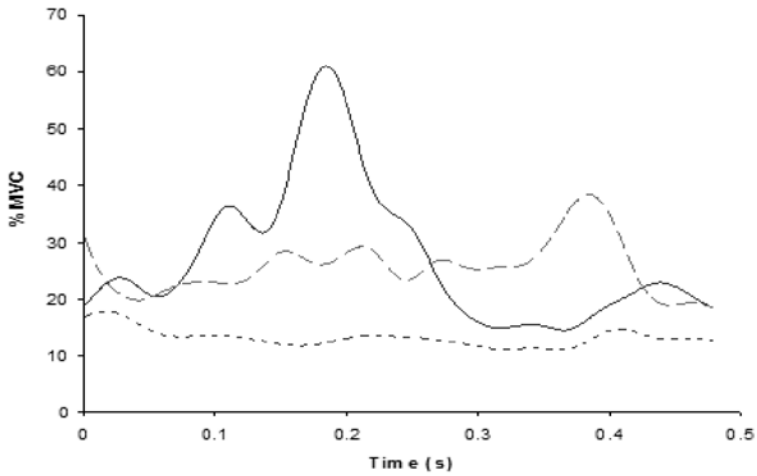
170 Oliveira et al.

Figure 6 — Example of one eggbeater kick cycle with a representation of the *Tibialis Anterior* (dotted line), *Adductor Logus* (dashed line), *and Gastrocnemius* (solid line).
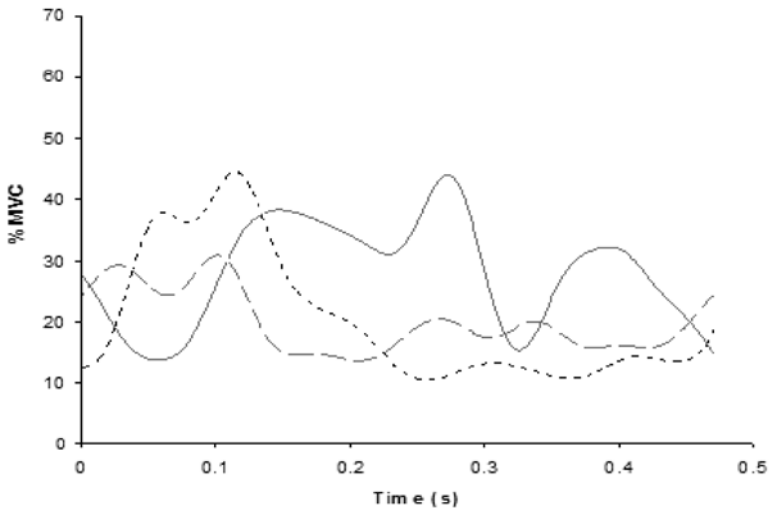

Figure 7 — Example of one eggbeater kick cycle with a representation of the *Vastus Medialis* (dotted line), *Biceps Femoris* (dashed line), *and Tensor Fasciae Latae* (solid line).

al., 2007), to the best of our knowledge no studies have recorded muscle activity for the eggbeater kick or have compared it during different body positions assumed in water polo. The lack of previous research highlights the originality of the present work. Unfortunately, the lack of previous research means that it was not possible to compare the current data with that from other studies.

Regarding the data we obtained, we observed that some muscles consistently showed higher EMG values in the same phase of the movement regardless of the type of positional variation during which the eggbeater kick was performed. This fact seems to indicate that positional variations did not clearly influence the eggbeater kick muscular activity patterns.

When observing each muscle individually, we detected that the *Tibialis Anterior* showed higher values during the outward phase. This could be explained by the *Tibialis Anterior*'s function to produce dorsi-flexion of the foot, which happens when the foot is being moved upward, backward, and outward (Sanders, 2005), along with the fact that high angular velocities are produced during dorsi-flexion for this phase of the movement (Homma, 2005). Surprisingly, the *Tibialis Anterior* revealed a tendency to show higher activation during the power phase, where no movement upward, backward, or outward occurs, than during the recovery phase (upward movement of the foot). This might be explained because some agonist/antagonist cocontraction occurs with the *Gastrocnemius Medialis*, which has high muscle activation in the power phase.

The results of the *Gastrocnemius Medialis* can be explained by the plantar flexion required during the eggbeater kick when moving the foot downward and forward (power phase; Sanders, 2005) because of the high angular velocities of plantar-flexion during the early portion of this phase (Homma, 2005). It seems that the *Gastrocnemius Medialis* muscle may be very important in the eggbeater kick proficiency during the power phase.

According to Sanders (2005), the quadriceps muscles (*Vastus Medialis*) are strong extensors of the knee during the eggbeater kick. In the current study, although high values were found during the power phase, the highest activation values for the *Vastus Medialis* actually appeared during the outward phase, precisely when the knee was being flexed. This might be explained by the activation level of the muscle being much higher on the beginning of the knee extension, which might occur later in the outward phase and when the knee is flexed while the leg is simultaneously laterally rotated. Another possible explanation might be related to the coactivation of the two antagonist muscles during that phase, which has been reported by some authors in the extension of the knee. This cocontraction must be necessary to perform other functions such as stabilization of the knee joint for an efficient motion of the leg in the power phase (Aagaard et al., 2000; Draganich, Jaeger & Kralj, 1989).

Using frequency analysis of muscle activation during the eggbeater kick, Klauck, Daniel, and Bayat, (2006) observed that the *Vastus Medialis* alternated between high and low frequencies of activation, while the *Adductor Longus* had a more regular pattern. In our study we observed similar results from the amplitude point of view, since the *Vastus Medialis* showed a higher difference in values between phases than did the *Adductor Longus*, which showed less variability in activation frequency. This muscle played an important role in the movement, showing high neuromuscular activation during the transition from outward to inward motion of the foot (Sanders, 2005), which happened mainly in the power phase and early recovery phase. Homma (2005) had reported little angular velocity during the adduction/abduction of the thigh, and since no high muscle activation was observed, it is possible to speculate that *Adductor Longus* does not have such an important role in the eggbeater kick proficiency as we originally anticipated. On the other

hand, we observed that the *Vastus Medialis* had a clear tendency to report higher muscle activity than the *Adductor Longus* (Klauck et al., 2006). We observed this same tendency in our study, because the *Vastus Medialis* showed higher values of EMG than the *Adductor Longus*, which might indicate that the *Vastus Medialis* (quadriceps) plays a more important role in the eggbeater kick than supposed.

The *Biceps Femoris* plays an important role in moving the foot backward and rotating it outward, while flexing the knee and laterally rotating the leg (Sanders, 2005). This function may explain the high activation of the *Biceps Femoris* that we observed during the outward phase. It is possible that, although the flexion of the knee occurs mainly during the recovery phase, higher EMG values may indicate that the knee is flexed during all the outward phase.

The *Tensor Fasciae Latae* muscle seems to have a more complex and less well defined activation pattern that did not allow us to clearly determine the phase in which its activation was highest. It seems that this muscle is more involved supporting the extension of the knee and the flexion of the thigh, rather than the medial rotation of the thigh and that perhaps it is not a prime mover during the eggbeater kick.

In general, it is possible to state that the *Vastus Medialis*, the *Gastrocnemius Medialis*, and the *Biceps Femoris* muscles showed clear peaks of activation, and conversely, the *Tibialis Anterior* and the *Adductor Longus* produced more constant patterns of activity without clear peaks (cf. Figure 6 and Figure 7). We note that the outward and the power phases of the eggbeater kick showed higher values of EMG as was expected because they are the phases that create the greatest kicking forces. These data suggest that the outward phase and early power phase are the periods of highest demand of muscle activity during the entire kick, which supports that, from the muscle activity point of view, the eggbeater kick cycle is a segmented and alternating rather than continuous action.

As we mentioned previously, we found no other studies that reported muscle activation values for the eggbeater kick. Other studies have reported values for the muscles we studied that may help us understand the findings of our study. Masumoto et al. (2007) and Kaneda, Wakabayashi, Sato, Uekusa, and Nomura (2008) conducted studies on deep-water walking and running, respectively, while Duc, Bertucci, Pernin, and Grappe (2008) studied muscles percentages amounting to 10–67% of muscle activity using uphill cycling. Their results suggested to us that some muscles require moderate muscle activation, while others demand very high muscle activation to perform the eggbeater kick.

During a water polo match as well as during learning/training conditions, players must perform the eggbeater kick for different technical and tactical tasks (Clarys, 1975; Smith, 1998).These changing tasks mean that the observed alteration of EMG responses in different muscles may be influenced by several task factors (e.g., changing body positions, different workloads, the opponent player, different playing positions). The continuously changing game context is very common in competition, as well as during learning/training context. These changes suggest that specific EMG patterns in each playing condition can be expected and should be characterized and compared. In the current study, we considered three positional variations for the eggbeater kick. Looking at the data corresponding to the comparison between the eggbeater kick position variations, it seems clear that the condition with the arms held up overloads the player the most and requires the

highest muscle activation to produce the greatest hydrostatic and hydrodynamic lift forces to overcome the weight required to support the torso, head, and arms in the air. The horizontal position seemed to show slightly higher level of activation than the basic position, but not as high as observed for the arms up position. These results confirmed the data obtained by Clarys (1975), which observed higher relative pressure percentages for eggbeater performed in vertical rather than in the horizontal position. These results suggest that the EMG patterns and the levels of muscular activation on the eggbeater kick are not very sensitive to variations in body position.

Conclusions

The peak EMG values for muscles occur at different instants in time during an eggbeater kick cycle. The results of our study showed that different muscles contribute differentially during the eggbeater kick cycle, changing as a function of the three different movement phases. Higher muscular activation was observed for the outward and power phases of the kick as would be expected. When changing and comparing the positional variations of the eggbeater kick, we observed some differences. Increasing the workload by putting the arms up produced much higher muscle activations, creating a clear overload on the lower limb muscles of the player. When changing body position to the horizontal position, muscles seemed to present similar activation compared with the basic position.

References

Aagaard, P., Simonsen, E.B., Andersen, J.L., Magnusson, S.P., Bojsen-Moller, F., & Dyhre-Poulsen, P. (2000). Antagonist muscle activation during isokinetic knee extension. *Scandinavian Journal of Medicine & Science in Sports, 10,* 58–67.

Aleksandrovic, M., Naumovski, A., Radovanovic, D., Geogiev, G., & Popovski, D. (2007). The influence of basic motor abilities and anthropometric measures on the specific motor skills of talented water polo players. *Physical Education and Sport, 5,* 65–74.

Basmagian, J.V., & De Luca, C. (1985). *Muscles Alive: Their functions revealed by electromyography* (4th ed.). Baltimore, MD: The Williams and Wilkins Company.

Clarys, J.P. (1975). Efficiency of breaststroke and freestyle swimming. In J.P. Clarys & L. Lewillie (Eds.), *Swimming II* (pp. 241–246). Baltimore, MD: University Park Press.

Clarys, J.P. (1983). A review of EMG in swimming: Explanation of facts and/or feedback information. In A.P. Hollander, P.A. Huijing, & G. de Groot (Eds.), *Biomechanics and Medicine in Swimming* (pp. 123–135). Champaign, IL: Human Kinetics Publishers.

Dopsaj, M., & Matkovic, I. (1994). Motor activities during the game. *Fisical Culture, 4,* 339–347.

Draganich, L.F., Jaeger, R.J., & Kralj, A.R. (1989). Coactivation of the hamstrings and quadriceps during extension of the knee. *The Journal of Bone and Joint Surgery, 71,* 1075–1081.

Duc, S., Bertucci, W., Pernin, J.N., & Grappe, F. (2008). Muscular activity during uphill cycling: Effect of slope, posture, hand grip position and constrained bicycle lateral sways. *Journal of Electromyography and Kinesiology, 18,* 116–127.

Figueiredo, P., Fernandes, R., Sousa, A., Vilar, S., Pereira, S., Gonçalves, P., et al. (2007). Electromyografic analysis of the Deltoideus muscle in two types of arm recovery in front crawl. In R. Arellano, J.A. Sanchez, F. Navarro, E. Ortiz, E. & G. Contreras (Eds.), *Swimming Science I.* (pp. 153-158). Granada, Spain: Editorial University of Granada.

Gonçalves, P., Pereira, S., Vilar, S., Figueiredo, P., Sousa, A., Fernandes, R., et al. (2006). Underwater electromyograph system and his dialog with other instrumentation. *Portuguese Journal of Sport Sciences, 6*(1), 21.

Hermens, H.J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10,* 361–374.

Hohmann, A., Kirsten, R., & Kruger, T. (2006). EMG-model of the backstroke start technique. *Portuguese Journal of Sport Sciences, 6*(1), 38–39.

Homma, M. (2005). Coaching Points for the Technique of the Eggbeater Kick in Synchronized Swimming based on Three-Dimensional Motion Analysis. *Sports Biomechanics, 4,* 73–88.

Kaneda, K., Wakabayashi, H., Sato, D., Uekusa, T., & Nomura, T. (2008). Lower extremity muscle activity during deep-water running on self-determined pace. *Journal of Electromyography and Kinesiology, 18,* 965–972.

Klauck, J., Daniel, K., & Bayat, M. (2006). Goalkeeper's eggbeater kick in water polo: Kinematics, dynamics and muscular coordination. *Portuguese Journal of Sport Sciences, 6,* 58.

Masumoto, K., Shono, T., Takasugi, S-I., Hotta, N., Fujishima, K., & Iwamoto, Y. (2007). Age-related differences in muscle activity, stride frequency and heart rate response during walking in water. *Journal of Electromyography and Kinesiology, 17,* 596–604.

Palmer, M.L., & Epler, M.E. (1998). *Fundamentals of musculoskeletal assessment techniques.* Philadelphia, PA: Lippincott Williams & Wilkins.

Pereira, S.M., Vilar, S., Gonçalves, P., Fernandes, S., Fernandes, R., Roesler, H., et al. (2007). Electromyographic analysis of the flip turn technique. In H-J Menzel & M. Chagas (Eds.), *Proceedings of the XXV International Symposium on Biomechanics in Sports* (pp. 55-58). Ouro Preto, Brazil.

Rainoldi, A., Cescon, C., Bottin, A., Casale, R., & Caruso, I. (2004). Surface EMG alterations induced by underwater recording. *Journal of Electromyography and Kinesiology, 14,* 325–331.

Rebocho, M., Cancela, N., Liberal, S., Gonçalves, P., Figueiredo, P., Fernandes, R., et al. (2008). Electromyographical study of three different types of shot in water polo. *Journal of Sports Sciences, 26*(1), 16.

Rouard, A., Billat, R., Deschodt, V., & Clarys, J. (1993). Muscular activation in sweep movements of the upper limb in freestyle swimming. In H. Riehle & M. Vieten (Eds.), *Proceedings of the XIX International Society Biomechanics Congress* (pp. 781-782), Dunedin, New Zealand.

Sanders, R.H. (1999a). Analysis of the eggbeater kick used to maintain height in water polo. *Journal of Applied Biomechanics, 15,* 284–291.

Sanders, R.H. (1999b). A model of kinematic variables determining height achieved in water polo boosts. *Journal of Applied Biomechanics, 15,* 270–283.

Sanders, R.H. Strength, flexibility and timing the eggbeater kick. Available at: http://coachesinfo.com/category/water_polo/5/. Accessed January 12, 2005.

Smith, H.K. (1998). Applied physiology of water polo. *Sports Medicine (Auckland, N.Z.), 26,* 317–334.