Original Article

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Comparison of muscle activity during swimming and on the Biokinetic simulator

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Authors' Contribution: A – Study Design, B – Data Collection, C – Statistical Analysis, D – Manuscript Preparation, E – Funds Collection

Abstract

Introduction: The aim of the study is to evaluate the coordination similarity ratio of involvement of selected muscles (*m. pectoralis major; m. latissimus dorsi; m. obliquus externus abdominis; m. triceps brachii*) during the crawl swimming cycle as a target movement with imitation movement act. The research set comprised 16 elite swimmers specializing in crawl sprint tracks. *Methods:* The key research method was surface electromyographic analysis synchronized with video recording. The study was based on a quantitative description of electromyographic recordings of the observed movement acts. The research study has the character of an intra-individual and inter-individual comparative analysis of the coordination characteristics of the movement system. This is a sequential triangulation of a quantitative-qualitative approach and an intragroup case study with an experimental way of obtaining data. *Results:* Muscle activation of selected muscles during the crawl did not show a significant difference in effect size compared to the imitation movements on the Biokinetic swimming simulator.

Keywords: crawl, electromyography, swim, biokinetic swimming simulator

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INTRODUCTION

Many of the current publications highlight the significance of performance competences in individual sports [1-4]. In this context, emphasis is placed on the use of specific training and diagnostic means. The latest knowledge in the field of sport training [5], sport [6] and exercise physiology [7,8] or psychology [9] is being incorporated into the preparation of top athletes. Recent years have seen a significant advance in swimming performances, chiefly because of the inclusion of these significant components in the sport preparation of swimmers. As stated by Bompa and Haff [10], as well as Riewald and Rodeo [11], today´s top swimming training is characterized by specialized preparation. The success of the best swimmers depends on balanced training using state-of-the-art means, specific training stimuli and diagnostic tools. One of such tools is kinesiological analysis, which makes it possible to specify intra-muscular and inter-muscular co-ordinations of a specific locomotion movement.

The research was focused on the swimming style of crawl, which is implemented strength-wise mainly through the shoulder girdle. As stated by Hollander and Cabri [12] and Deschodt, Arsac Rouard [13], a swimmer gains about 85 % of his or her motive power by the activity of the upper limbs. Other studies, too, show a significant correlation between the strength of upper body muscles and swimming performance [14-16]. Emphasizing strength preparation in the overall concept of swimming training has a positive impact particularly on increasing the propulsion component of the swimmer´s movement in the water, extension of the swimming step and decrease in the frequency of strokes, characterizing progress in the development of special strength competences [17]. The development of swimmers´ strength competences is specific, as it takes place in two dimensions – in the aquatic environment and on dry land. The focus of strength preparation on the comprehensive musculoskeletal apparatus develops non-specific swimming strength, while the development of specific swimming strength is related to the sequence of muscle group engagement, movement speed, expenditure of effort and muscle tone duration. The development of specific swimming strength thus occurs in water or during exercises imitating swimming movements. In the common training practice, dryland preparation makes use of swimming simulators. These arterial devices are regarded as a special training tool for the development of the strength competences of the shoulder girdle. In addition, their use constitutes an integral part of the training plan of the Czech representation team. A question remains to what extent these acts of movement kinesiologically imitate individual swimmers´ strokes in the water.

The aim of the research was toz monitor muscle activation and to assess the degree of coordination similarity between the crawl style as a target movement and imitation and strength exercises outside the aquatic environment (on the Biokinetic swimming simulator) using electromyographic (EMG) measurement of muscle activity. This EMG method is currently perceived as an objectivization tool in the search for the coordination context of the work of the musculoskeletal system. It is referred to as one of the most widespread methods that is both accessible and highly precise. The specific conclusions of our research propose methodological recommendations as well as more general conclusions that can be related to the present knowledge of kinesiology and sport locomotion.

There are many existing studies dealing with the physiological aspects of individual swimming styles. However, there is no study which would demonstrably elucidate the kinesiological differences or similarities involving the engagement of upper body muscles during the performance of the crawl stroke cycle by an upper limb and during imitation movement acts.

MATERIAL AND METHODS

Subject

The study in question was a multi-case study involving an intra-individual assessment and a subsequent inter-individual evaluation of the results. The research was primarily based on a deductive process and testing carried out using the quantitative method. A comparative analysis was performed of the coordination characteristics of the musculoskeletal system with an experimental character of obtaining quantitative data. Methodology-wise, the sequential triangulation of the qualitative – quantitative approach was thus involved [18].

The key research method was surface electromyographic analysis synchronized with video recordings of the movement acts monitored. The study was based on the quantitative description of the electromyographic recordings of the movement acts monitored. The subject of the analysis was the timing of the onset of the activation of selected muscles, always right (*dx*) and left (*sin*). These are specifically these muscles: *m. pectoralis major; m. latissimus dorsi; m. obliquus externus abdominis; m. triceps brachii.* In relation to the proband's positions assigned in synchronized way and the mutual comparison of the correlation matrix of EMG curves among the individual muscles monitored. The quantified results of the EMG analysis were arranged intro matrices in the individual probands, allowing inter-individual comparison of movement stereotypes and their dynamics in the regime of correlation analysis.

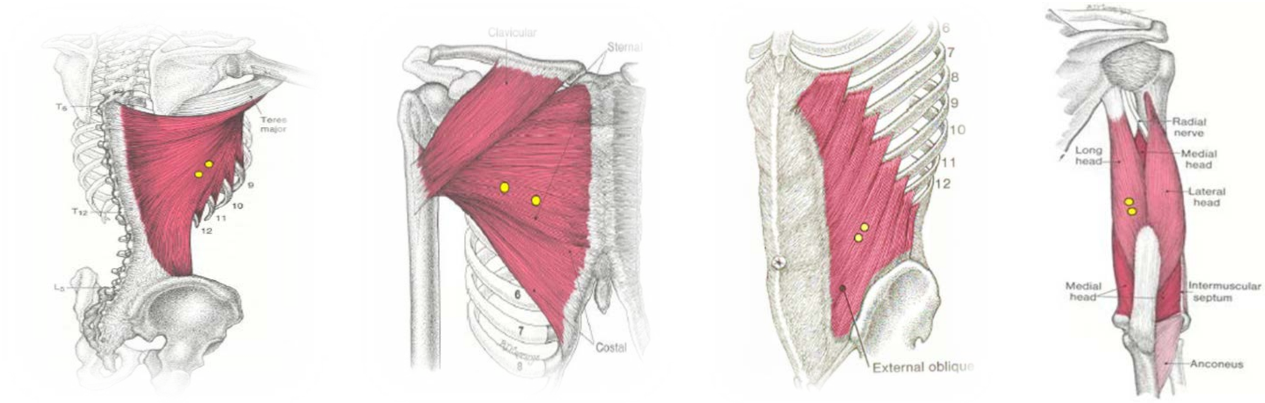
Through expert assessment, sixteen probands were chosen from a group of elite athletes pursuing a specific discipline – the 100-metre crawl. The quality of movement was guaranteed by their performance at the Czech representation team level, promising excellent coordination and fixation of the movement stereotype, as well as high muscle work efficiency. They were experienced professional swimmers, who had undergone several (at least 8) years of special swimming training and took part in international competitions and world cup competitions. All the probands were male. These characteristics guaranteed sufficient homogeneity of the research set. The age of the probands was 17–27 years (the average age was 23.2 ± 2.8 years); their height was 180–197 cm (the average height 187 ± 5,4 cm); their weight was 72–91 kg (the average weight 81.5 ± 5.4 kg); the length of their swimming practice was 8–17 years (the average length of practice 13 ± 2.7 years); the time of the 100-metre crawl was 49.1 – 53.8 sec (the average time 52.4 ± 1.2 sec).

Protocol

The testing took place in the FLUM training pool and in the sport motor skills lab of the Faculty of Physical Education and Sport of Charles University in Prague. It is the equipment of the LD-Pool company marked as Super Pro A7. The tank is 2.3 m wide, 5 m long and 1.15 m deep; the shafts ensure constant water flow. They are propelled by seven engines fed by 400V/32A, with the total output of 21 kW, and are able to generate water flow with the speed of 0,5 - 2,5 m × s^{-1} in the tank. The technical specifications further state that the engines are able to pump 98 000 1 × min^{-1} [19]. The stream in the tank can be regulated using a control panel that divides the engine output into sixteen degrees, with a speed increase by one degree representing an acceleration of the stream by 0.04 to 0.22 m × s^{-1}. The movement of the proband in the FLUM swimming simulator was enabled by a counterflow, set individually for each proband. The speed was equivalent to 85% of the proband´s personal maximum during the 100m freestyle swim.

Another measurement was conducted on the Biokinetic swimming simulator. This ergometer is a digital meter measuring in kilopond units, resistance generated using a direct-current dynamo, 9-point scale, range 20 – 600 W. The resistance is set by an electromagnetic system. The resistance of the system increases directly in proportion to the strength exerted by the swimmer. The microprocessor and continual data flow make it possible to change the braking force intensity depending on the direction or speed during one stroke, thus simulating resistance in water more efficiently. The programme equipment enables communication with the interface and the additional count of the basic parameters measured in real time [20].

In all probands, measurements of the movements monitored were made in and out of the aquatic environment during one day under identical conditions. Each proband was subjected to the measurement of two 20-second sequences of crawl strokes in a swimming flume and two 20-second sequences of strokes on the Biokinetic swimming simulator. The measurements themselves were performed after a standard warm-up exercise.



A B C D

Figure 1. Localization of the electrodes on: A - latissimus dorsi muscle, B - m. pectoralis major, C - m. obliquus abdominis externus, D - m. triceps brachii [21].

To obtain the electromyographic recording, the mobile 14bit EMG apparatus ME6000 Biomonitor was used (manufacturer: MEGA Electronics, Ltd., Finland); subsequent technical specifications: signal type EMG – rough/average/RMS/unified with the measuring range of ± 8192 μV; 16 measuring channels; sampling frequency of up to 10000 Hz; apparatus sensitivity1 μV per degree; band pass filter 8–500 Hz; internal memory: 256 MB – 2 GB; possibility of wireless monitoring of the recording; resolution: 14 bit; dimensions 181 × 85 × 35 mm; weight: 344 g, software MegaWin. 5 mm diameter disc bipolar electrodes Ag/AgCl were used for the imaging (measuring gel area 154 mm2 and impedance 400 Ω), attached via a cable with a signal pre-amplifier *(MEGA Electronics Ltd., 2010).* The electrodes were always placed on both the right and left half of the body in the direction of the muscle fibres according to the manufacturer´s specifications. Following pictures 1A-1D represent the placement of electrodes in individual muscles.

To secure the electrodes and the amplifier in the aquatic environment, instructions of the methodology for WaS-EMG, i.e. EMG recorded in the aquatic environment, were followed [19,20]. To synchronize the video camera with EMG recordings, wireless triggers were used. The swimmer´s movement was recorded from the lateral view by the digital video camera Olympus TG-2 with the imaging speed of 240 images/s, resolution Full HD (1920 × 1080), video format H. 264.

Before the measuring itself, a test was carried out to ensure the reliability of the results. The water temperature in the flume was about 28 °C (± 0.5 °C), which is within the range of the recommended temperature for the conduct the WaS-EMG experiment [22]. The air temperature was about 29 °C (± 0.5 °C).

Statistic

The synchronization of the EMG recording and the video recording, the graphic depiction, as well as the assessment and comparison of the data obtained were performed in specific Megawin software. Additional data were processed using the Matlab programme, suitable for statistical and graphic analysis. EMG curves were evaluated by available methods in context with assigned differentiated positions of the motor system.

Ethics

The research project was approved by the Ethics Committee of Charles University at the Faculty of Physical Education and Sport on 31st March 2014 under reference number 117/2014. The processing of the results and their presentation took place anonymously, but was confirmed by the informed consent of all probands.

RESULTS

A relevant section of the movement cycle was selected semi-automatically by expert assessment in individual probands in every situation measured (swimming flume, Biokinetic swimming simulator) for all the muscles monitored. This meant a removal of the sections between the first movement cycle and the movement cycle with a stable pattern of muscle coordination without artefacts. In this part, the resulting data of one proband are indicated first, followed by the overall data of all the probands. In all, 715 movement cycles were evaluated. The following figures (5-8) show the results of the detection of muscle activity of the measured signal recording in all the monitored muscles of proband no.1 in all measured situations (in the following order: the swimming flume, the Biokinetic swimming simulator). Thin blue curves in the graph mark the envelopes of the measured electromyographic signal from the individual movement cycles interpolated to a uniform length of 0 to 100 % of the cycle, and their average – the average envelope – is marked bold red. The red vertical line marks activation maximums and the vertical cyan line marks activation minimums. The beginning of the movement cycle begins at 0% and ends at 100 %. The time information involving the course of the average cycle is normalized to percentages because of better and clearer interpretation. In the following figures, two movement cycles are shown in order to accentuate periodicity.

Figure 2 shows the recording of the detection of the muscle activity of m. pectoralis major dx. It can be seen that the average position of the first activation of m. pectoralis major dx. in the flume stood at 32 % of the movement cycle, whereas the decrease in the activity of the first activation occurred at 68 %. The position of the second activation of the muscle stood at 91 % of the movement cycle and the decrease in the activity of the second activation occurred, on average, at 8 % of the cycle. On the Biokinetic swimming simulator, the average position of the first activation stood at 1 %; the decrease in activity was at 38 %. The position of the second activation as at 77 % and its decrease at 90 %.

Figure 3 shows the recording of muscle activity of m. latissimus dorsi dx. As mentioned above, this muscle was selected as a reference muscle, which is why in all the three situations measured, the position of activation is at 0 % (100 %). What is different is the average position of the decrease in the activation of this muscle; it is found at 19 % in the flume, at 13 % on the Biokinetic swimming simulator and at 28% on the expander.

Figure 4. shows the recording of the muscle activity of m. external abdominal oblique dx. The average muscle activation position in the flume stood at 18 % of the movement cycle, whereas the decrease was at 28 %. On the Biokinetic swimming simulator, the average position of the first activation stood at 29 %; the decrease in activity was at 53 %.

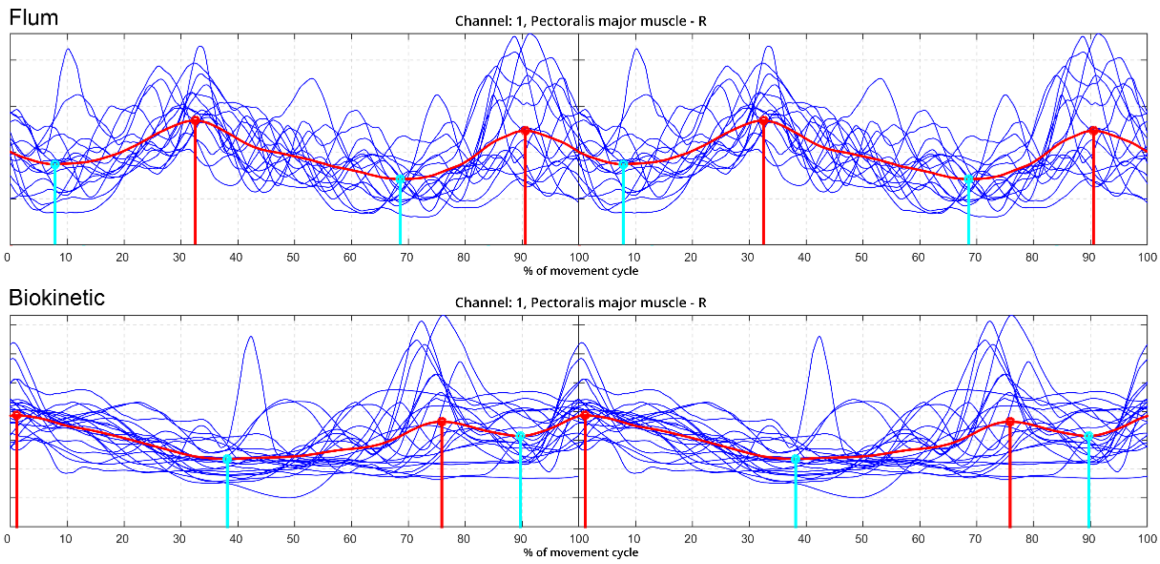


Figure 2. Detection of the muscle activity of m. pectoralis major dx. of proband no. 1

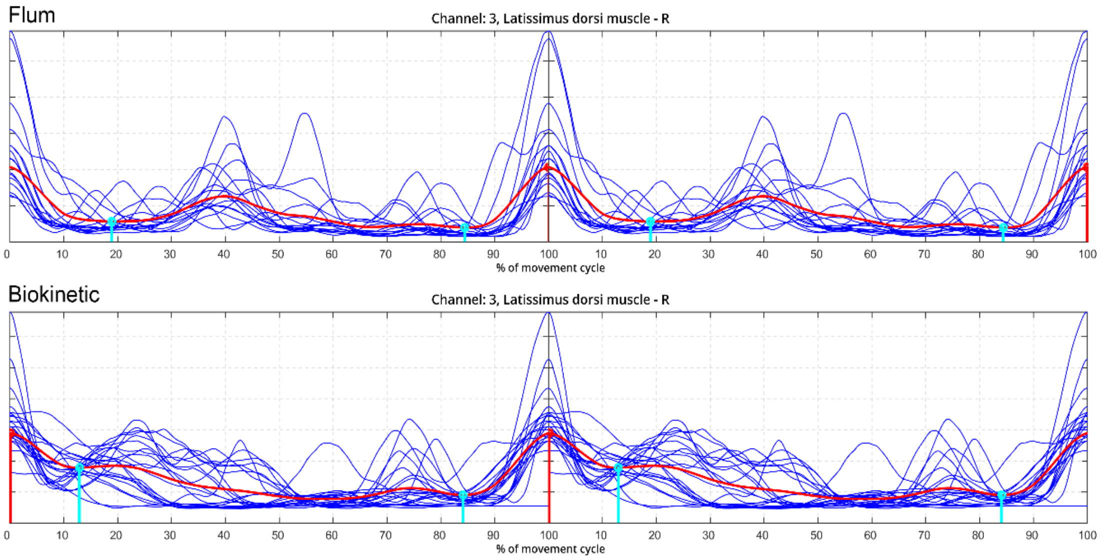


Figure 3. Detection of the muscle activity of m. external abdominal oblique dx. of proband no. 1

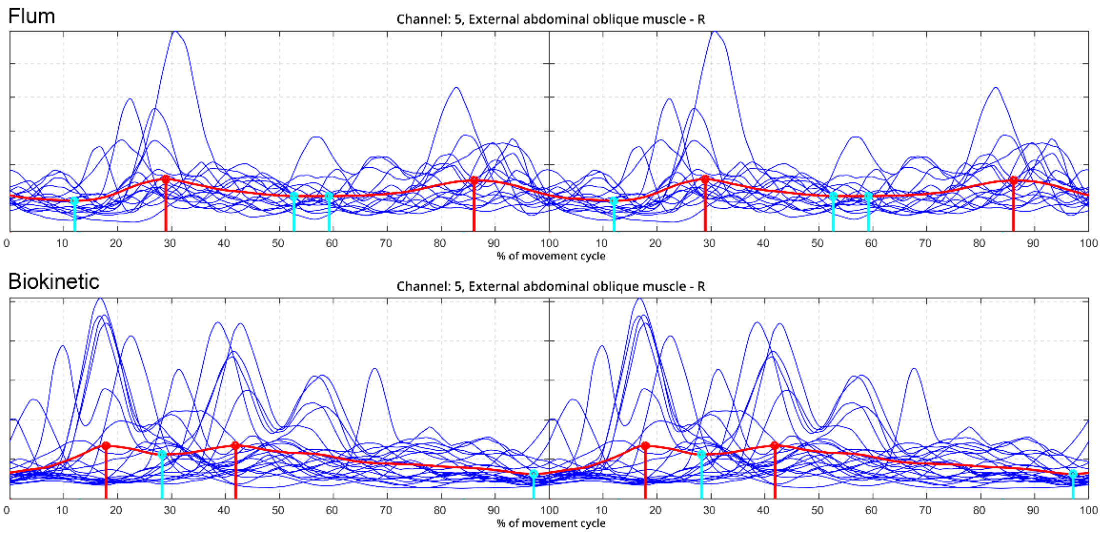


Figure 4. Detection of the muscle activity of m. external abdominal oblique dx. of proband no. 1

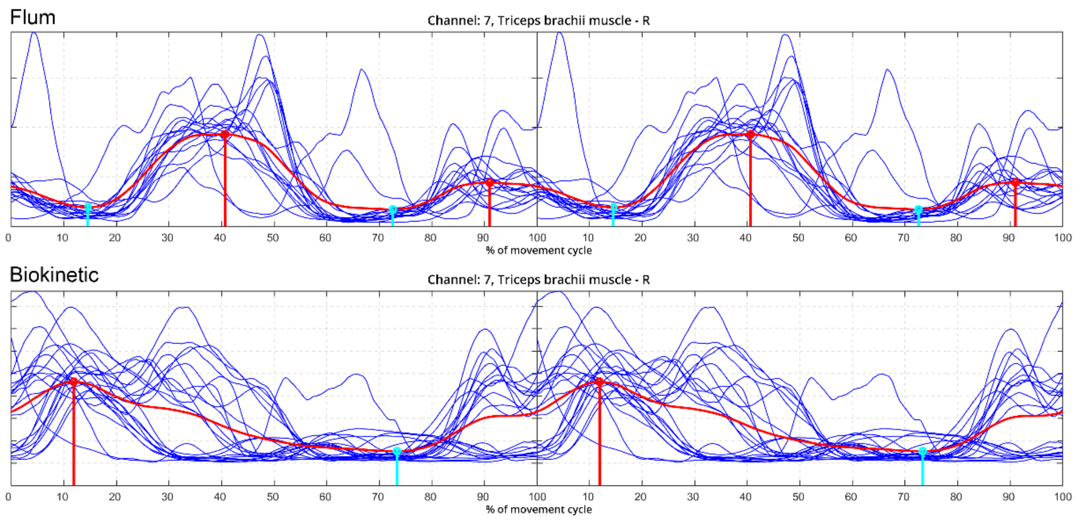


Figure 5. Detection of the muscle activity of m. triceps brachii dx. of proband no. 1

Table 1. Wilcoxon's test of the muscle activity of all probands (n16).

Muscles	Statistical units	Z - score	p-value	eff. size
m. pectoralis major dx	median	0.052	0.959	0.013
	Q1	0.103	0.918	**0.227**
	Q3	0.310	0.756	0.026
	SD	0.155	0.877	**0.227**
m. pectoralis major sin	median	0.490	0.624	**0.122**
	Q1	0.367	0.713	0.092
	Q3	0.573	0.567	**0.143**
	SD	0.447	0.655	**0.112**
m. latissimus dorsi dx	median	1.603	0.109	**0.401**
	Q1	0.341	0.733	0.085
	Q3	1.551	0.121	**0.388**
	SD	1.551	0.121	**0.388**
m. latissimus dorsi sin	median	0.982	0.326	**0.246**
	Q1	0.398	0.691	0.099
	Q3	0.672	0.501	**0.168**
	SD	1.034	0.301	**0.259**
m. obliquus abdominis ext. dx	median	0.879	0.379	**0.220**
	Q1	0.341	0.733	0.085
	Q3	0.362	0.717	0.090
	SD	1.603	0.109	**0.401**
m. obliquus abdominis ext. sin	Mdn	0.259	0.796	0.065
	Q1	0.682	0.496	**0.170**
	Q3	0.879	0.379	**0.220**
	SD	0.465	0.642	**0.116**
m. triceps brachii dx	median	0.621	0.535	**0.155**
	Q1	0.170	0.865	0.043
	Q3	0.414	0.679	**0.103**
	SD	0.362	0.717	0.090
m. triceps brachii sin	median	0.931	0.352	**0.233**
	Q1	0.738	0.460	**0.185**
	Q3	1.655	0.098	**0.414**
	SD	0.621	0.535	**0.155**

SD - standard deviation; Q1 - first quartile; Q3 - third quartile,; z – z-score; p-value; eff. size – r (small-size effect > 0.1; medium-size effect > 0.3; large-size effect > 0.5)

Figure 5 clearly shows the recording of the muscle activity of m. triceps brachii dx. The average muscle activation position in the flume stood at 40 % of the movement cycle; the decrease was at 73 %. On the Biokinetic swimming simulator, the average activation position stood at 12 %; the decrease in activity occurred at 74 %.

Following Table 1 contains the results of the Wilcoxon's test of all measured muscles of all probands, comparison of Flum and Biokinetic results. Significant size effect is marked bold.

DISCUSSION

To make things clearer, the following part of the discussion focuses on the individual muscles monitored. The description of muscle behaviour is always based on the graphs of the course of the EMG signal in an average movement cycle obtained in all three measurement types in the following order – the aquatic environment (flume), the Biokinetic swimming simulator. The benefits and limitations of this study are also discussed at the end of this section.

Musculus latissimus dorsi

On the basis of semi-automatic analysis, it is possible to observe the activation of m. latissimus dorsi in the swimming cycle in the aquatic environment in most probands in the stroke phase. During the stroke phase, scapular protraction occurs, with the arm in adduction, elbow extension and inner rotation occurs in the shoulder joint. This activity is clearly connected with the extension of the shoulder joint humerus, which is one of the main functions of this muscle. It can be seen that the engagement of this muscle follows the activation of m. pectoralis major, which generates the initial movements of the stroke phase by the clavicular part. These results are in accordance with the study by Lomax et al. [23] and other authors [24,25], who regard these two muscles as dominant in the creation of propulsion force, especially in the stroke part of the swimming cycle. Other electromyographical studies also show that together with m. rectus abdominus and m. gluteus maximus, m. latissimus dorsi is one of the most active muscles in crawl-style swimming. Another important function of the muscle is its function of an auxiliary breathing muscle, conditional on the creation of the fixed point (*punctum fixum*) by the humerus. As implied by the resulting graphs of most probands, after the activation of m. latissimus dorsi, the locomotion activity moves from the dorsal to the ventral side of the torso thanks to the position of the arm in the final part of the stroke phase, and the movement is finished by the homolateral muscle m. obliquus abdominis externus.

The completion of the extension in the shoulder joint in the stroke phase under water is the main reason for the second maximum measured in some probands. Similar results were obtained by the research of Caty et al. [26], who also mentions the second activation of. latissimus dorsi in his conclusions. We believe that in some probands, the second activation of the muscles is caused by the distinctive swimming technique of each individual. This corresponds with the results of most studies [27,29] dealing with the monitoring of muscle activity during swimming, which also confirm high individual variability.

On the Biokinetic swimming simulator, m. latissimus dorsi is activated once. The engagement of the muscle occurs later than during the measurement in the aquatic environment. Differences can be found in the length of activation, with the resulting graphs showing that on the swimming simulator, the muscle was activated throughout the stroke phase. This is undoubtedly related to the fact that the resistance of a mechanical device is involved in the simulator. The strength of load on Biokinetic is precisely regulated by a specially adjusted dynamo in such a way that the proportional resistance of the system grows with the swimmer´s force applied. In an ideal case, therefore, the movement speed should be constant. Moreover, the muscle does not need to contribute to the stabilization of the body in the same way as in water. As evident from the results, statistically significant results between the situations measured cannot be presumed in the muscle activity of m. latissimus dorsi dx. However, materially significant differences were established between the situations measured, where we can speak about a significant effect.

Musculus pectoralis major

The graphs of the activation of this muscle reveal that it engages at the beginning of the swimming cycle in the aquatic environment. This means that the activation occurs more during the flexion phase of the arm, which would point at the anti-gravitation function of this muscle, resulting from its adduction function in four-legged mammals.

It is evident that m. pectoralis major initiates the propulsion phase of the stroke, which is in accordance with Colwin [29], who call this phase "water catch". Vodicka [30] argues that during swimming, the time of activation of m. pectoralis major precedes the time of activation m. latissimus dorsi by 7 % - 10 %. These two muscles provide the strength to perform the first part of the stroke, the so-called pull, and they also participate to a greater extent in the second part of the stroke, the so-called push. The main function of m. pectoralis major is the adduction with inner rotation in the shoulder joint and as an auxiliary muscle, it participates in flexion. We believe that the aquatic environment allows the performance of the locomotion propulsion action in the centred position of the shoulder joint, manifesting, among others, by the curved S-shaped trajectory of the stroking arm. This stroke technique was common before 2000, but in today´s professional swimming there has been a change of this technique, especially in sprints, manifesting primarily in the activity of m. pectoralis major. Therefore, it is also in the activation of this muscle that we find a great individual variability. In the crawl style, the upper limb of the stroke is outstretched cranially during the initiation phase, due to the extension of the stroke trajectory, the shift of the centre of gravity and the improvement of torso stability. In this phase, some probands engage m. pectoralis major to a greater extent (and, as we may speculate, also the unmeasured m. rectus abdominis). Likewise, Colwin [29] claims that the preparatory phase is the most variable of the whole the swimming cycle, the reason being the impact of swimming intensity and individual style deviations. And, naturally, so are the swimmer´s individual competences, such as joint mobility, length of levers, work of the limbs. Although the probands monitored were experienced professional swimmers with a specialization in sprint tracks, a high individual coordination variability was yet again discovered in the activation of m. pectoralis major. We presume that this difference is determined by the uniqueness of each proband´s swimming style. This can, of course, be verified and assessed from the video recording material using the trajectory of the upper limb analysis, which could certainly be the subject of further follow-up research. M. pectoralis major also has an auxiliary and a reinforcing breath function, especially during the fixation of the upper limb, of which supporting oneself against water can be considered an example.

The biggest activation of m. pectoralis major on Biokinetic occurs in the phase of maximum flexion in the shoulder joint achieved by the proband on the simulator. The phases during which m. pectoralis major is activated the most on the simulator, is the transition between the ascending and descending phase of the arm. Contrary to activation in the flume, here, the activation of this muscle is markedly separated from the subsequent activation of m. latissimus dorsi. In the aquatic environment, there is a smooth transition between the activations of these two muscles. Contrary to the trajectory of the stroking arm in the flume, here, the movement of the upper limb is conducted along the shortest possible route. This trajectory differentiation indicates the distinctness of the movement stereotype in the aquatic environment. Again, we can speak about a high individual variability. As implied by the results, there were no statistically significant differences in the muscle activity of m. pectoralis major between the situation measured in the flume and on Biokinetic.

Musculus obliquus externus abdominis

The analysis of the resulting graphs has found that m. obliquus externus abdominis in the aquatic environment has more of a stabilizing character. The resulting EMG curves reveal a visible contraction but imperfect relaxation, because the muscle is still in light tension – torso stabilization. These conclusions were in accordance with Vodička [30], who has conducted a comparative analysis of selected coordination indicators of the crawl swimming technique and spontaneous crawling. Kracmar [31] states that m. obliquus abdominis externus performs torso flexion during a bilateral action and turns the torso contralaterally in a unilateral action. The work of the abdominal muscles tends to be complex; their separate function manifests in stabilization work. The synergic function of some muscles becomes a functional unit with their engagement in stereotypes. The work of contralateral mm. obliqui abdomini ext. and int. is performed jointly, and it is bound in a firm union within the oblique abdominal muscle chain. With the fixed point punctum being deposited cranially in the shoulder joint area, they rotate the pelvis to the side of m. obliquus ext. abdominis. It is evident that this torso rotation during the crawl swimming technique facilitates the transfer of the arm by the shoulder being partially extended above the water, which decreases the overall resistance of the aquatic environment.

We believe that m. obliquus abdomini ext. as one of the torso stabilizers is an integral part of an efficient stroke, providing a systemic link between the movement of the upper and lower limbs.
The bench of the Biokinetic swimming simulator represents a fixed point for the proband, which is why m. obliquus abdominis externus can serve especially a stabilizing function to prevent torso rotation during the movement of the upper limbs, which is not necessary during swimming simulator exercise, as there is no phase of extension and transfer above the longitudinal axis of the body. The differentiated position corresponding to maximum activation is closer to extension in the shoulder joint.

As already mentioned, m. obliquus abdominis externus ensures torso rotation in the opposite direction. If, therefore, the torso is in the rotation position on one side, this muscle then fixates the pelvis by holding it in an optimum position and compensating torso rotation. The engagement of the muscle is found in a completely different differentiated position compared to the swimming cycle in the flume. Because it is one of the key muscles on the ventral part of the torso, we regard this different timing as an important marker of the differences in the movement stereotypes of the simulator and swimming.

On the basis of the results of Wilcoxon´s test, statistically significant differences between the situations measured cannot be deduced in the muscle activity of m. obliquus abdominis ext. From the point of view of material significance, however, we can speak about a medium-size effect.

Musculus triceps brachii

As evident from the resulting graphs, there is gradual engagement of m. triceps brachii during the final propulsion phase. It starts in the place where the palm is close to the longitudinal axis at the lower chest level. The movement of the arm changes and is directed backwards, outwards and upwards. This is how the propulsion phase ends, with the entire arm moving to extension, the duration of which is determined by the technique of the individual probands´ swimming movement, the swimming speed and the size of the angle of the deflected torso along the longitudinal axis. When analysing the muscles measured, we found that during the movement stereotype of individual probands, there were modifications within the length of the activation of m. triceps brachii. We believe that the degree of extension in the elbow joint in this phase depends on the individual mastery of the swimmer´s technique; in particular, on the phase of the transition from the stroke phase to the transfer phase. Similar results are also reported by Lauer et al. [28] and Olstad et al. [32]. At the end of the push, complete extension in the probands´ elbow joint did not take place. The end of the muscle activity of m. triceps brachii in the aquatic environment ends in the upper thigh area. This part of the swimming cycle, where the stroke phase of pulling changes into the pushing phase, is characterized by changes in the speed of the stroking arm, with a decrease in speed occurring. In addition, in the transfer phase of the swimming cycle we also noted a second activation of m. triceps brachii in some of the probands monitored, just before their arm entered the water. We believe that the activation is due to an eccentric contraction, when the muscle, in co-activation with m. biceps brachii, directs the speed of the arm at the end of the transfer phase. These conclusions are in accordance with the EMG study by Lauer et al. [28], who verified the co-activation of m. biceps brachii and m. triceps brachii with ten elite swimmers. When comparing the resulting graphs, the movement stereotype in water appears more stable than during the simulation.

The resulting graphs of the activation of m. triceps brachii on the bench of the Biokinetic swimming simulator show a marked activity at the end of the stroke phase as well. The activation of the muscle on the simulator is markedly longer than in the aquatic environment. The probands end their movement cycle in complete dorsal flexion in the shoulder joint, which, as already mentioned, is counterproductive during the stroke phase in the aquatic environment.

The limits of this work were mainly the conditions given by the specifics of the aquatic environment and the limitations resulting from the use of the surface electromyography method. The advantage of this method is the possibility of direct analysis and objectification of motion from a functional point of view. Great emphasis is placed on adhering to a precise methodological procedure, as the electrical signal could be distorted, whether during the application of electrodes, when sensing or evaluating the EMG signal. In the case of our study, it was mainly about respecting the specifics of measuring EMG in the aquatic environment, such as the use of a waterproof bag for the amplifier, special bipolar electrodes, covering waterproof stickers and greater caution in evaluating artifacts that are more common in water.

We are aware that there are a number of quality studies on the correlation between strength and swimming performance [11-14] and the results are contradictory and do not always support the claim of a positive transfer of strength acquired in dry preparation for swimming performance. It is obvious that no simulation device allows the strengthening to take place along a complex 3D trajectory, which is the result of the anatomical structure of the shoulder girdle and the hydrodynamic properties of water. Nevertheless, Biokinetic is considered a special training tool for the development of strength skills of the shoulder girdle. The magnitude of the load on the simulator is precisely regulated by a specially adjusted dynamo so that with the applied force of the swimmer, the proportional resistance of the system directly increases. Its use is also an integral part of the training plan of the Czech national team.

Our study did not show statistically significant differences in the time activation of the monitored muscles during the swimming cycle using the crawl technique and the use of this swimming simulator. We believe that at the present time of the Covid-19 coronavirus pandemic, when many countries are facing restrictions on swimming training due to the closure of swimming pools, the use of Biokinetics can be chosen as an alternative to swimming training.

CONCLUSION

On the basis of the results obtained, it can thus be stated that the muscle activation of selected muscles during an average work cycle in the crawl style did not show statistically significant differences in comparison with the imitation movements on the Biokinetic swimming simulator. However, materially significant differences between the engagement and synergies of most muscles were demonstrated We assume that the application of the knowledge from our research can complement the theoretical context and a detailed description of the engagement of muscles during the swimming cycle and during imitation movement acts. On the basis of the data established, it will be possible to design training procedures and formulate a conclusion regarding a recommendation for using specific imitation exercises.

Although the results of the paper submitted suggest that there are no statistically significant differences between the situations measured, materially significant differences were demonstrated. Therefore, it is vital that these relations are viewed with certain respect. The issue investigated is still at the stage of searching for suitable directions that will lead to more effective objectivization of the results as the number of studies continues to increase.

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