Original Article

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Kinesiological analysis of involvement of selected muscles during a crawl swimming technique

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Abstract

The aim of this study is to present a project to assess the level of coordination similarities in the wimming cycle as a target motion with simulation and fitness exercises, in order to evaluate the effectiveness of examined activities and their use as a training resource. Electromyographic (EMG) easurements of selected muscles (*m. pectoralis major dx, sin; m. latissimus dorsi dx, sin; m. obliquus externus abdominis dx, sin; m. triceps brachii dx, sin*) were performed on expertly selected professional wimmer when swimming with the use of the crawl technique in the aquatic environment and training with the use of different devices out of water (swimming simulator, expanders). Based on the results, se of expanders appears to be preferable alternative to swimming training for the selected individual.

Keywords: crawl, electromyography, swim, swimming trainer

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INTRODUCTION

Swimming is a complex multi-level system of completely specific relationships between a wide range of factors. Due to a specific aquatic environment, the effective development of swimming skills cannot be replaced by any other activity. Nevertheless, training outside of the aquatic environment is an integral part of the training process, especially the strength training of a swimmer. Swimming is replaced in this environment by other types of locomotion with a similar kinesiological motion, according to the literature [1–3].

For a better level of swimming training and higher chance for a swimmer's success, the level of strength abilities is also essential in performance swimming [4,5]. Therefore, muscle strength development is also an essential part of swimming training and an important prerequisite for a racing success. Our study focuses on a crawl swimming technique, which is mainly powered by shoulder joints. As stated by Clarys et al. [6] and Deschodt, Arsac Rouard [7], approximately 85 % of the driving force that the swimmer acquires is obtained just by the activity of the upper limbs. Further research also shows a significant correlation between the muscle strength of the upper half of the body and the swimming performance [8–10]. Therefore, the improvement in the strength of the shoulder joint also results in an increase in the maximum force, which is also reflected in higher swim speeds, especially in sprints [11,12]. Garrido et al. [13] stress that the development of strength of swimmers should be mainly carried out in the water but also on the ground. Other authors also state that both types of training complement each other, therefore a large variety of training units occurs. However, there are studies that call into question the advantages of strength training on dry land [1,14,15]. Maglischo [3] argues that training on dry land should primarily develop the strength needed, when swimming with the use of the so-called specific swimming strength. Perfect coordination of muscle interaction is generally more important for performance prospects than a gross increase in strength for example. Hofer [16] also claims that the effect of using the strength of large muscle groups involved in motion is made possible by the fine motor function of the acral parts of the limbs. The coordination of large muscle groups with fine acral motor function is probably the reason for a large volume of only specialized swimming training of performance swimmers. By developing strength, while working out on fitness machines and obtaining high functional indicators by non-specific means, this exact coordination, called the "water sensation", is not developed.

For swimming training on dry land, rubber expanders and swim simulators are common practice. According to Kristofic [17] advantage of the expanders is their simplicity, low acquisition costs and versatility of use. They allow almost perfect imitation of swimming motion, for virtually all swimming techniques. Their disadvantage will begin to emerge in development of strength-endurance. At higher load values, in proportion to the workload, the level of resistance also increases. At this phase, the requirement for relaxed and relatively slow shift of the limb to the starting position is compromised. On the contrary, backwards motion is accompanied by receding muscular effort, as the limb would be thrown forward with considerable force. There is an undesirable distortion of movement leading to ineffective activation of some muscle groups.

Load value of swimming simulators is more precisely regulated. Resistance is set, for example, by an electromagnetic system (Biokinetic). The proportional resistance of the system increases with the force of the swimmer. „Comparing the performance on a simulator and a regular swimming performance can help to determine the extent to which a swimmer is able to realize his strength-endurance abilities for his propulsion" [16]. It is reported in a significant study of swimming training on land [12] that the disadvantage of swimming benches (Biokinetic) may be the neglect of the role of lower limbs and rotation of the torso.

Imitative exercise on a swimming simulator and exercises with rubber expanders are considered a special training tools especially for the development of the strength of the upper limbs and is also included in the training plan of the Czech representation team. The question, however, remains to what extent these kinesiological actions imitate the crawl technique of individual swimmers in the water. There are many research papers dealing with the physiological aspects of each swimming method. However, there aren't any studies that would conclusively illustrate the kinesiological differences or similarities of the involvement of upper body muscles in the upper limb crawl cycle and imitative motion acts.

MATERIAL AND METHODS

This is a case study with an intraindividual evaluation using analysis. Surface electromyographic (EMG) analysis was used to obtain the data. Research is based on a deductive process and testing. Intraindividual analysis was used to compare the time of onset of muscle activation during the observed cycle. The quantification of the EMG analysis of the selected individual's measured element was assembled into matrixes that allowed an intra-individual comparison of the motion stereotype and its dynamics in the correlation analysis mode.

Expert judgment was made for a deliberate selection of one individual from a group of top athletes of a specific discipline – 100 meters of crawl. The quality of the movement was ensured by performance at the level of a national representation team, therefore excellent co-ordination and fixation of the movement stereotype and high efficiency of muscle work can be expected. Parameters of the monitored individual: male 22 years, 186 cm, 80 kg, right upper limb laterality.

Measurement was carried out in two sequences each lasting 20 seconds:

1. during swimming technique of crawl in the aquatic environment (swimming flume);
2. imitative motion on a swimming simulator (Biokinetic);
3. during imitative workout exercise using expanders (Ippon 2.5 m).

ad 1) The swimming flume at the Faculty of Physical Education and Sport of the Charles University in Prague creates conditions for uninterrupted movement against the flow of water with the possibility of setting the current speed in the range from 0.5 $m \cdot s^{-1}$ to 2.5 $m \cdot s^{-1}$. The dimensions of this simulator are 6 x 2.5 x 1.2 m. The water flow is created by shafts, which are placed in the tubes under the double bottom, thus ensuring a smooth flow of water.

ad 2) Swimming ergometer Biokinetic – digital tool measuring in kilopond units, resistance with DC dynamo, 9-point scale, range 20–600 W. Resistance is controlled by an electromagnetic system. Resistance of the system increases proportionally with the force of the swimmer.

ad 3) Ippon expander is made of braided rubber-rope, equipped with swimming paddles. Length 2.5 m.

For recording of the electromyography, a mobile 14-bit EMG ME6000 Biomonitor was used (Mega Electronics, Kuopio, Finland) with 16 available channels. Sampling frequency at 10000 Hz / channel with measuring range ± 8192 μV for EMG. Sensitivity of the instrument 1 μV per unit, band pass through 8-500 Hz. Possibility of recording into 2GB internal memory or wirelessly straight into a PC. We used the Kendall Ag/Cl hydrogel electrodes, connected using a cable with a preamplifier

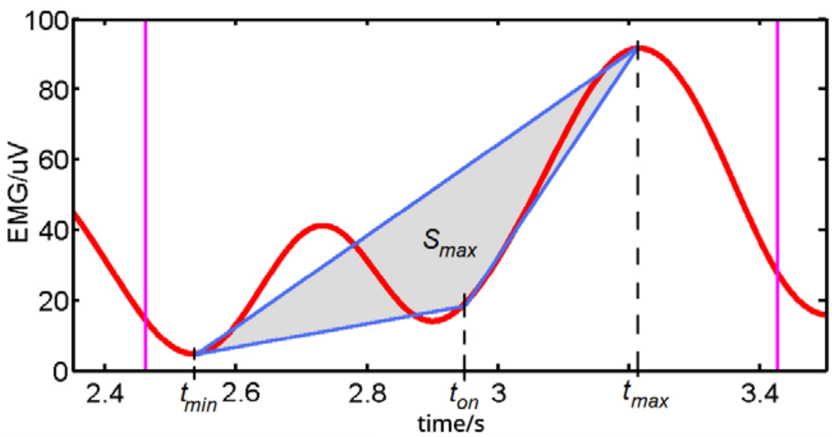

Figure 1. Triangular detection of the onset of muscular activity on the EMG envelope (red): t_{min} is the location of the local minimum, t_{max} of the local maximum and the ton is the beginning of muscle activity detected. S_{max} denotes the triangle with the largest surface, vertical lines represent the boundaries of the motion cycle.

(Mega Electronics, Finland). Due to the zero waterproofing of EMG ME6000, we used an auxiliary person who stood in a sufficient distance from the aquatic environment during measurements in the flume. To minimize the limitation of the individual's motion, all cables leading from the electrodes to the device were tied into a single six-meter braid.

The electrodes were positioned so that a connecting line between their centers was in the direction of the muscle fibers at the point of the greatest muscle tension during the simulation of the assessed motion [18]. Location of electrodes was expertly assessed by a physiotherapist. The electrodes have been cleaned, degreased with medical alcohol and eventual body hair was removed. In order to eliminate the occurrence of artifacts, the SENIAM guidelines (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) for selection and location of electrodes were followed.

The data obtained were evaluated in MatLab, MegaWin, Microsoft Excel and Dartfish. Complex analysis of EMG records was performed using the Matlab computer program. The maximum crosstalk matrix of EMG records of individual muscles in one particular motion and the respective phase shifts were determined, from which the timing of the activation of individual muscles in the chosen movement was determined. This order was intraindividually compared. Intraindividual comparison analysis was performed on the basis of the modified correlation function of two signals as recommended by Hojka et al. [19] and was used to evaluate the similarity of muscle pair activation based on the Spearmen correlation coefficient. To determine the time of onset of muscle activation with subsequent intraindividual analysis of the selected section, triangular detection of the beginning and end of the activity, which is currently used as the most accurate method, was chosen [20]. Within the cycle, a maximum was located within ± 10 % of cycle from the average envelope position. In the same way a minimum is found and then the point considered as the beginning of muscle activity is marked by the triangular method, which is the point below the line connecting minimum with the maximum, which together with the two points creates a triangle of the largest possible surface (Figure 1). A similar procedure is used to find the end of muscular activity, but we used the minimum located behind the maximum. For both points (a start and an end of muscle activity), the absolute position and the relative position within the motion cycle is recorded. If more than one maximum is detected on the average EMG envelope, repeat this procedure for the next maximum, resp. muscle activity intervals.

Subsequently, the activity intervals of the individual muscles in individual motion cycles were portrayed graphically. These ranges were averaged; besides the average position of the beginning and the end of the activity, the standard deviations of these values were also determined. Average activity intervals were also graphically displayed. For a greater clarity, 50 % of the preceding cycle and 50 % of the following cycle are inserted in the graph, so the displayed stretch ranges from −50 % to 150 % of the movement cycle; see Figure 2.

RESULTS

The results are shown in the following tables and charts. One of the types of outputs of the collected data is the graph in Figure 2. This graph captures the activation of the measured muscle within the individual motion cycles. For each muscle, the average position of activation within the motion cycle (in percent of the cycle) and the standard deviation are determined. The same is used for the deactivation of the muscle. The 0–100 % range on the horizontal axis of the chart corresponds to one movement cycle.

The line of each muscle leads (on the left) from the (average position of activation − SD) through the thin line (average position of activation) to the stronger line (average position of activation + SD) and continues through the strongest part to the right. From the location (average position of deactivationv − SD) the thinner line leads to (average position of deactivation) and ends with the thinnest (average position of deactivation + SD). If a bigger number of activity sections within a motion cycle were detected in a given muscle, more lines appear. The horizontal axis within fields captures more than one cycle in order to better illustrate periodicity.

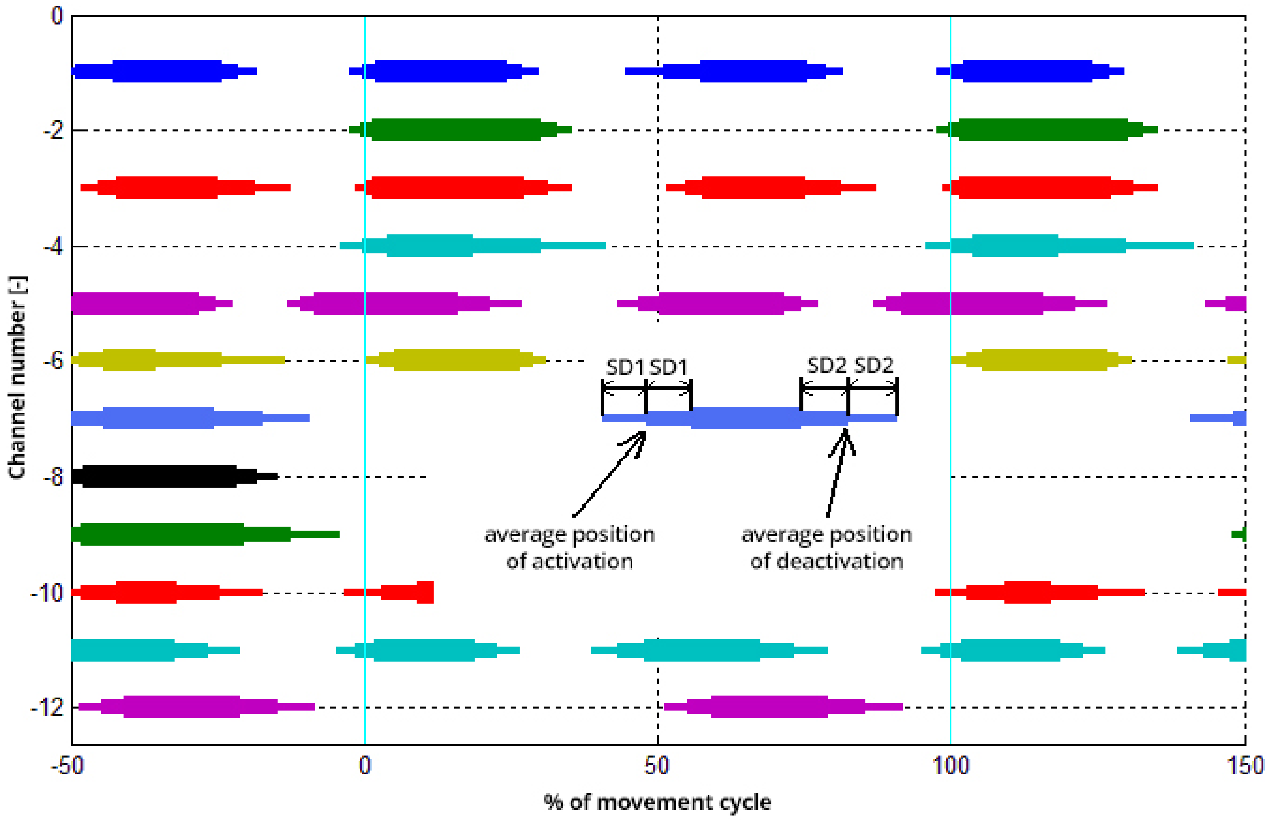

Figure 2. Activation of a measured muscle within individual cycles of motion (explanation of graphs).

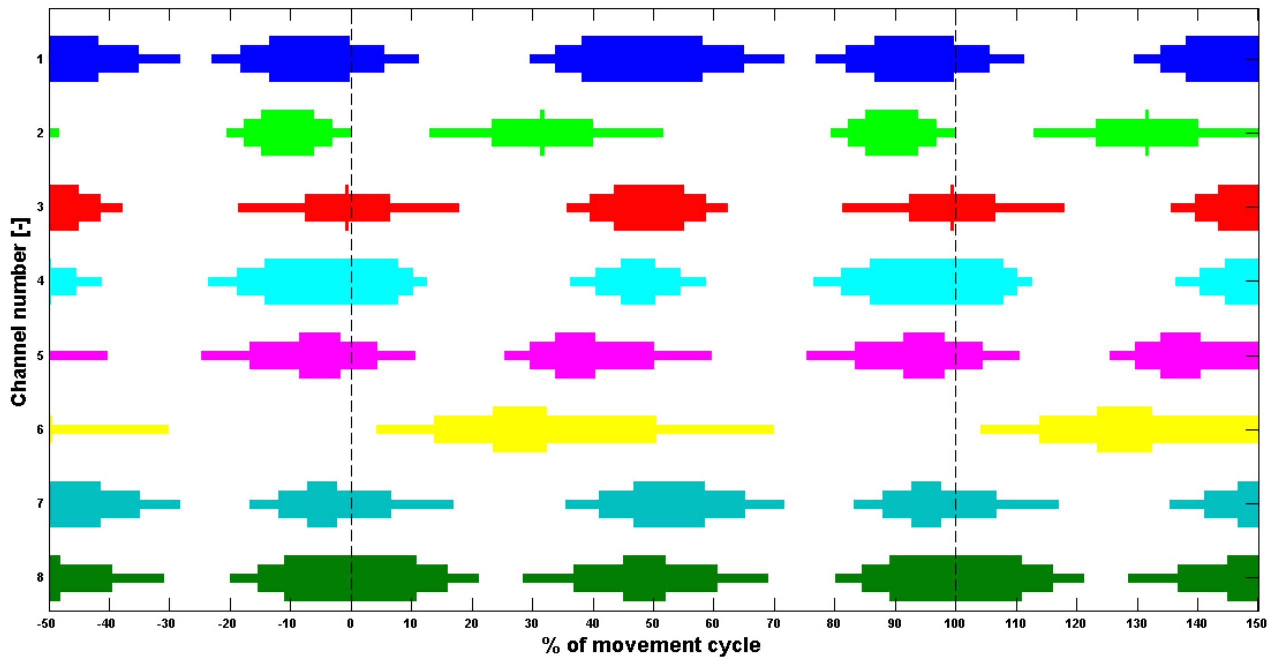

Figure 3. Intervals of muscle activity in the aquatic environment. Channel number: 1 – Pectoralis major muscle, dx; 2 – Pectoralis major muscle, sin; 3 – Latissimus dorsi muscle, dx; 4 – Latissimus dorsi muscle, sin; 5 – External abdom. ob. muscle, dx; 6 – External abdom. ob. muscle, sin; 7 – Triceps brachii muscle, dx; 8 – Triceps brachii muscle, sin.

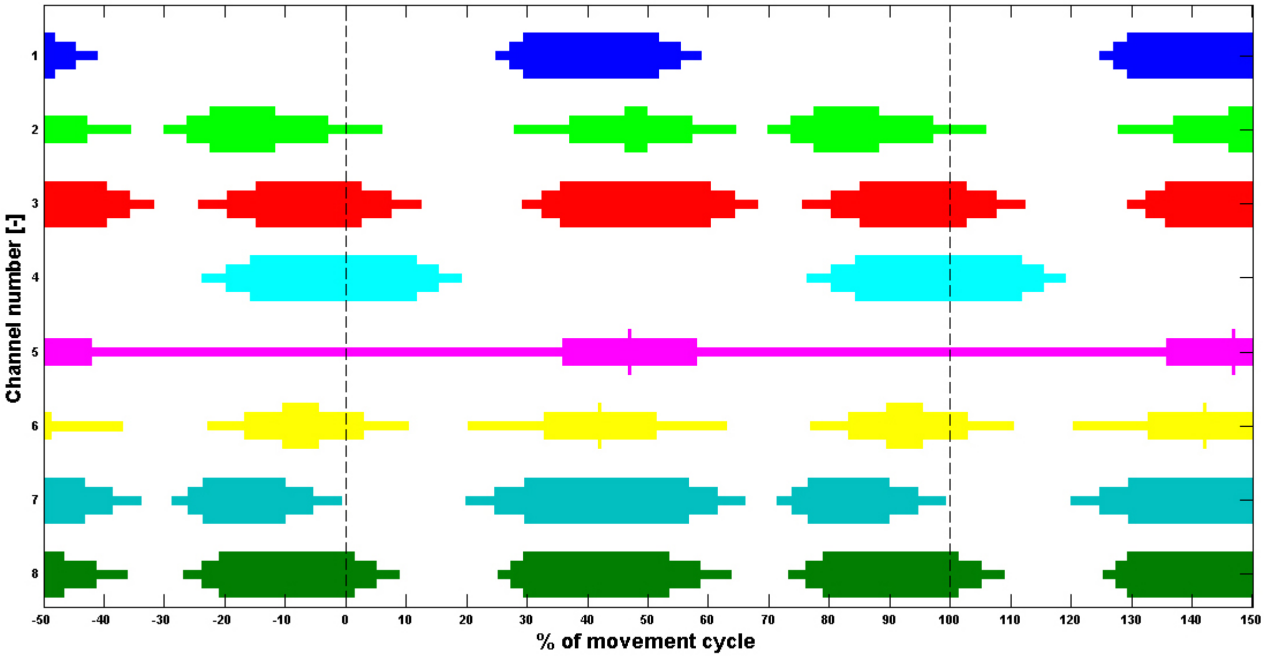

Figure 4. Intervals of muscle activity within the swimming cycle using the expander. Channel number: 1 – Pectoralis major muscle, dx; 2 – Pectoralis major muscle, sin; 3 – Latissimus dorsi muscle, dx; 4 – Latissimus dorsi muscle, sin; 5 – External abdom. ob. muscle, dx; 6 – External abdom. ob. muscle, sin; 7 – Triceps brachii muscle, dx; 8 – Triceps brachii muscle, sin.

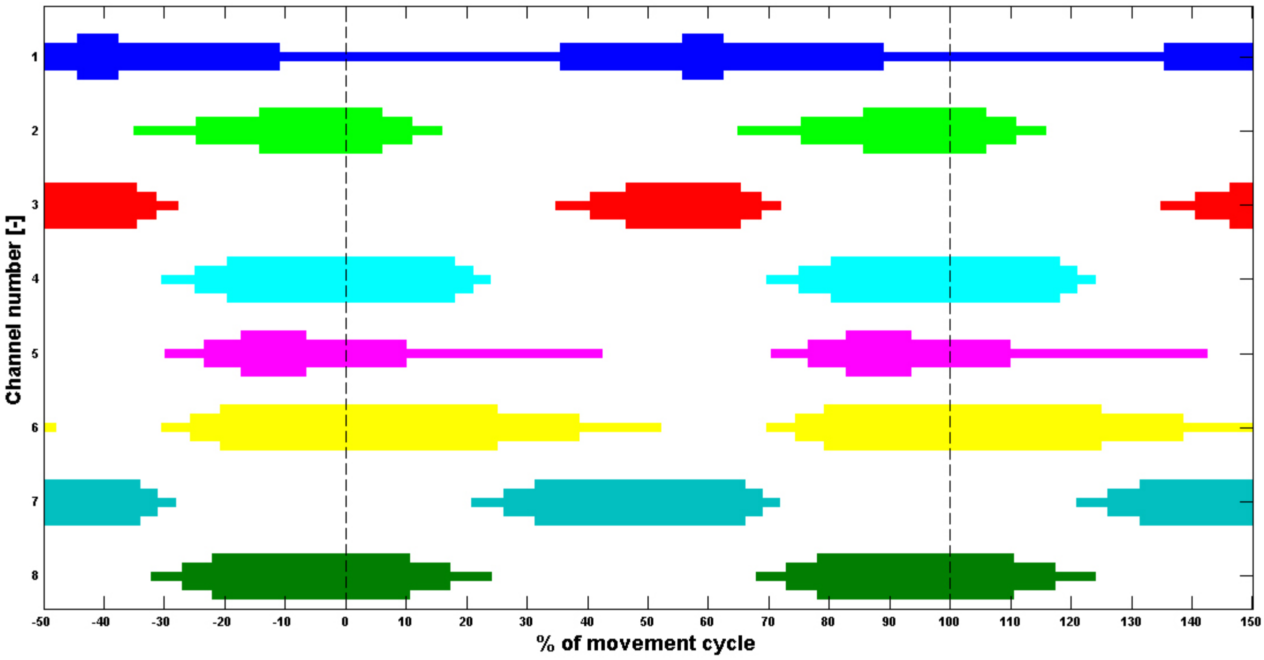

Figure 5. Intervals of muscle activity within the swimming cycle using Biokinetic. Channel number: 1 – Pectoralis major muscle, dx; 2 – Pectoralis major muscle, sin; 3 – Latissimus dorsi muscle, dx; 4 – Latissimus dorsi muscle, sin; 5 – External abdom. ob. muscle, dx; 6 – External abdom. ob. muscle, sin; 7 – Triceps brachii muscle, dx; 8 – Triceps brachii muscle, sin.

Table 1. The average position of muscle activation in the observed cycle

Muscles	FLUME activation		Expander activation		Biokinetic activation	
	Mean [%]	SD [%]	Mean [%]	SD [%]	Mean [%]	SD [%]
Pectoralis major muscle, dx	33.77	4.25	26.97	2.29	35.40	20.18
Pectoralis major muscle, sin	15.49	7.47	24.72	10.28	75.21	10.37
Latissimus dorsi muscle, dx	66.50	3.29	30.44	6.19	40.48	5.76
Latissimus dorsi muscle, sin	77.27	4.12	76.94	3.42	74.92	5.41
External abdom. ob. muscle, dx	73.51	13.46	47.56	5.67	76.44	6.19
External abdom. ob. muscle, sin	57.94	13.77	32.71	12.51	74.31	4.81
Triceps brachii muscle, dx	39.84	3.67	24.66	4.79	26.07	5.21
Triceps brachii muscle, sin	23.40	2.12	24.80	5.52	72.87	4.98

Table 2. Timing of onset of monitored muscles (swimming flume, Biokinetic simulator)

Muscles	FLUME [rank]	Biokinetic [rank]	d	d squared
Pectoralis major muscle, dx	3	2	−1	1
Pectoralis major muscle, sin	6	3	−3	9
Latissimus dorsi muscle, dx	7	8	1	1
Latissimus dorsi muscle, sin	4	1	−3	9
External abdom. ob. muscle, dx	1	7	6	36
External abdom. ob. muscle, sin	8	6	−2	4
Triceps brachii muscle, dx	5	5	0	0
Triceps brachii muscle, sin	2	4	2	4
Σ	—	—	—	64

Spearman's rank correlation coefficient $r_s = 0.238$; effect size $r_s^2 = (0.238)^2 = 0.0566 = 5.66\ \%$

Table 3. Timing of the onset of monitored muscles (swimming flume, expanders)

Muscles	FLUME [rank]	Expander [rank]	d	d squared
Pectoralis major muscle, dx	3	4	1	1
Pectoralis major muscle, sin	6	5	−1	1
Latissimus dorsi muscle, dx	7	7	0	0
Latissimus dorsi muscle, sin	4	1	−3	9
External abdom. ob. muscle, dx	1	2	1	1
External abdom. ob. muscle, sin	8	8	0	0
Triceps brachii muscle, dx	5	6	1	1
Triceps brachii muscle, sin	2	3	1	1
Σ	—	—	—	14

Spearman's rank correlation coefficient $r_s = 0.833$; effect size $r_s^2 = (0.833)^2 = 0.6938 = 69.38\ \%$

DISCUSSION

The reference muscle to which everything was related was chosen as the *m. latissimus dorsi dx* as the main engaging muscle for locomotion of a shoulder joint. As can be seen from the results *m. latissimus dorsi* activates in one swimming cycle in the aquatic environment (flume) two times up to a maximum in a close proximity. *M. latissimus dorsi* performs adduction, internal rotation and extension in the shoulder joint. The maximum peak emg activity of *m. latissimus dorsi* alternates with the activation of the *m. pectoralis major*. As the main muscle for locomotion of shoulder joint, it begins to work at the beginning of the engaging phase. Then, due to the position of the arm in the final part of the engagement phase, the locomotion activity moves from the dorsal side of the torso to the ventral side and the movement is completed by the homolateral *m. obliquus abdominis externus*. The completion of the extension in the shoulder joint during the engagement phase of motion below the water level is the reason for the second maximum measured by the *m. latissimus dorsi*, whose action after dragging the hand over the body axis is taken over the *m. obliquus abdominis externus dx* which rotates the torso. This torso rotation makes the transfer of the arm easier by pulling the shoulder partially above the surface, which reduces the overall resistance of the aquatic environment. Partial rotation of the torso and reduction in proximity of the side of the body to the water surface on the side of the transferred arm reduces the requirements for mobility in the shoulder joint, supports the so-called high elbow position, while allowing relaxation of the muscles of the arm. As shown in the above graphs, the activation of *m. obliquus abdominis externus* in the aquatic environment is more phasic, postural. *M. triceps caput longum* is the main extensor of the elbow joint, it helps in dorsal flexion and adduction in the shoulder joint. As the results show, its maximum activity is evident at the end of the engagement phase. As shown in Figure 2, activity of *m. triceps caput longum* is rather pronounced. This phenomenon is seen with the excellent swimmers due to a moment when the swimmer strives for the maximum length of the engagement phase.

In exercising with expanders outside the aquatic environment, *m. latissimus dorsi* completes the extension in the shoulder joint during the engaging phase of movement. The activation of *m. latissimus dorsi* starts later than when measured in the aquatic environment due to the gradually increasing resistance of the rubber expander. The internal rotation is secured against less resistance by the internal rotator – *m. pectoralis major*, which is almost non-involved, it acts as a synergist of the *m. latissimus dorsi*. *M. obliquus abdominis externus* is a muscle that ensures rotation of the torso to the opposite side. Thus, if the torso is in a rotational position on one side, then this muscle fixes the pelvis so that it holds the pelvis in the optimal position and compensates for the rotation of the torso. We find the involvement of the muscle in a completely differentiated position compared to the swimming cycle in the flume. Since this is one of the most important muscles on the ventral side of the torso, we consider this different timing to be the decisive marker of distinction for this the movement stereotype. In contrast, the activity of *m. triceps caput longum* is very similar to activation in the aquatic environment. Here we believe that this is again due to the excellent technique of the individual, who has internalized movement stereotype and even strokes outside the aquatic environment are ended a dorsal flexion in the shoulder joint and an extension in the elbow joint.

Bench of the swimming simulator is a *puntum fixum* for the individual, therefore the *m. obliquus abdominis externus* can retain a stabilizing function. To avoid the rotation of the torso, which is unnecessary during exercise on the simulator as the pullout and transfer phase over the longitudinal axis of the body does not occur. The differentiated position corresponding to the maximum activation is closer to the extension of the shoulder joint and is closer to swimming than to the expander exercise. When using Biokinetic, *m. pectoralis major* is most active at the maximal flexion in the shoulder joint that the individual achieves on the simulator. Phases in which the m. pectoralis major activates the most are transitions between the ascending and descending phases of the arm. Unlike flume activation, activation of this muscle is significantly distinct from the subsequent activation of *m. latissimus dorsi*. In the aquatic environment, the activation of these two muscles switches fluently. The activation of *m. triceps caput longum* is also significantly different here. From the results above, it is evident that the level of muscular coordination is very important in elite sport [18-20].

CONCLUSION

The timing of muscular activation of selected muscles measured during the crawl swimming technique in the aquatic environment was more consistent with the timing of muscle activation using a rubber expander than when using a swimming simulator. Based on these findings, it appears that using an expander as an alternative to swimming training is more appropriate. *M. latissimus dorsi dx* was chosen as the reference muscle to which everything was related as it is the main propulsion muscle for locomotion of the shoulder joint. We assume that the application of the acquired knowledge from our research will help to complement the theoretical context and the detailed description of the engagement of the muscles during the swimming cycle and the imitation movement acts. On the basis of the findings, it will be possible to compile training procedures and to conclude on the recommendation for the use of specific imitative exercises.

REFERENCES

1. Tanaka H, Costill DL, Thomas R, Fink WJ, Widrick JJ. Dry-land resistance training for competitive swimming. Med Sci Sport Exerc 1993; 25(8):952–959.
2. Crowe S, Babington J, Tanner D, Stager J. The relationship of strength to dryland power, swimming power, and swimming performance. Med Sci Sports Exerc 1999; 31(5):S255.
3. Maglischo EW. Swimming fastest. Champaign (Illinois): Human Kinetics; 2003.
4. Costill DL, Reifield F, Kirwan J, Thomas R. A computer based system for the measurement of force and power during front crawl swimming. J Swim Res 1986; 2:16–19.
5. Girold S, Maurin D, Dugué B, Chatard J-C, Millet G. Effects of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances. J Strength Cond Res 2007; 21(2):599. doi:10.1519/R-19695.1.
6. Clarys JP, Toussaint HM, Bollens E, Vaes W, Huijing PA, De Groot G, et al. Muscular specificity and intensity in swimming against a mechanical resistance - surface EMG in MAD and free swimming. 1988;191–9.
7. Deschodt VJ, Arsac LM, Rouard AH. Relative contribution of arms and legs in humans to propulsion in 25-m sprint front-crawl swimming. Eur J Appl Physiol Occup Physiol 1999; 80(3):192–199. doi:10.1007/s004210050581.
8. Toussaint HM, Hollander AP. Energetics of competitive swimming: implications for training programmes. Sport Med 1994; 18(6):384–405. doi:10.2165/00007256-199418060-00004.
9. Hawley JA, Williams MM. Relationship between upper body anaerobic power and freestyle swimming performance. Int J Sports Med 1991; 12(1):1–5. doi:10.1055/s-2007-1024645.
10. Aspenes S, Kjendlie P-L, Hoff J, Helgerud J. Combined strength and endurance training in competitive swimmers. J Sport Sci Med 2009; 8:357–365.
11. Strzala M, Tyka A. Physical endurance, somatic indices and swimming technique parameters as determinants of front crawl swimming speed at short distances in young swimmers. Med Sport 2009; 13(2):99–107. doi:10.2478/v10036-009-0016-3.
12. Morouco P, Keskinen KL, Vilas-Boas JP, Fernandes RJ. Relationship between tethered forces and the four swimming techniques performance. J Appl Biomech 2011; 27(2):161–9. doi:10.1123/jab.27.2.161.
13. Garrido N, Marinho DA, Reis VM, van den Tillaar R, Costa AM, Silva AJ, et al. Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? J Sport Sci Med 2010; 9(2):300–310.
14. Trappe SW, Pearson DR. Effects of weight assisted dry-land strength training on swimming performance. J Strength Cond Res 1994; 8(4):209–13. doi:10.1519/00124278-199411000-00001.
15. Sandhu JS, Kaur S, Shenoy S. A correlative study between aerobic, anaerobic dry land performances and swimming performance in professional indian swimmers. Brazilian J Biomotricity 2012; 6(3):185–192.
16. Hofer Z. Technika plaveckých způsobů. Praha (Czechia): Karolinum; 2011. [in Czech]
17. Kristofic J. Kondiční trénink 207 cvičení s medicinibaly, expandéry a aerobary. Praha (Czechia): Grada Publishing; 2007. [in Czech]
18. Balko S, Borysiuk, Z, Balko I, Spulak, D. The influence of different performance level of fencers on muscular coordination and reaction time during the fencing lunge. Arch Budo 2016; 12(1): 49-59.
19. Boloban VN, Tereshchenko IA, Otsupok AP, Krupenia SV, Kovalenko YO, Otsupok AnP. Perfection of coordination with the help of jump exercises on trampoline. Physical Education of Students, 2016; 20(6): 4-17. doi:10.15561/20755279.2016.0601
20. Skladanivska IV. Assessment of nervous-muscular system's potentials of cyclic kinds of sports sportsmen. Pedagogics, Psychology, Medical-Biological Problems of Physical Training and Sports, 2016; 20(4): 29-34. doi:10.15561/18189172.2016.0405