Ovidius University Annals, Series Physical Education and Sport / SCIENCE, MOVEMENT AND HEALTH
Vol. XVI, ISSUE 2 Supplement, 2016, Romania
The journal is indexed in: Ebsco, SPORTDiscus, INDEX COPERNICUS JOURNAL MASTER LIST, DOAJ DIRECTORY OF OPEN ACCES JOURNALS, Caby, Gale Cengace Learning, Cabell's Directories

Science, Movement and Health, Vol. XVI, ISSUE 2 Supplement, 2016
September 2016, 16 (2, Supplement): 293-300
Original article

BIOMECHANICAL ANALYSIS OF FRONT CRAWL ARM STROKE AND LEG KICK BY TACHOGRAPH MEASURING SYSTEM

BÁTOROVÁ Michaela[1], MOTYČKA Jaroslav[1], ŠŤASTNÝ Jan[1], LEPKOVÁ Hana[1]

Abstract[*]

Aim: In our case-study contribution we will present the results of crawl technique measurements with the tachograph measuring method, where we focus on analysing the crawl arms stroke and legs kick. This research aims to present a biomechanical analysis of the crawl legs kick (range, position of legs – the angle of kick, frequency, depth of kick *etc*.) and how the measured parameters influence the efficiency and speed of crawl legs. Another aim is to present a biomechanical analysis of the crawl arm angles and frequency and their impact on the speed and efficiency of crawl arms swimming techniques. Measurements were performed with six racing swimmers of the Czech national swimming team. A partial aim is also providing information on further developments in measuring techniques with accelerometers at the Brno University of Technology (BUT).

Methods: For measurements of swimmers, we used the Tachograph measuring system together with a system of underwater cameras. For processing the results from the tachograph, we used the Swim Data Viewer software, which is part of the measuring system. For measuring angles, we used a video recording program MB-Ruler. For processing of the results, we used Excel, Matlab and for their evaluation, we used linear regression.

Results: In the results of our case study of 6 male swimmers from the Czech national swimming team, Hypothesis 1 was confirmed (swimmers with a deeper arm stroke have a higher mean speed). Hypothesis 2 (mean speed is decreasing with decreasing frequency) was not confirmed. Hypothesis 3 (swimmers with a greater angle of arm stroke also have a higher mean speed) was confirmed. Hypothesis 4 (swimmers with a deeper kick have lower mean speed) was not confirmed. Hypothesis 5 (swimmers with a deeper kick have lower efficiency) was not confirmed. For Hypothesis 6, the dependence of mean speed on the frequency was only slightly positive, and thus statistically insignificant. Hypothesis 7 (swimmers with higher frequency of kicks have higher efficiency of crawl legs) was confirmed.

Conclusion: Thanks to the results of this case study, the future direction of development research and analysis of swimming techniques will be outlined, the results will be forwarded to swimming coaches in the next phases of research and they will influence the training preparation of the national swimming team of the Czech Republic.

Keywords: biomechanical analysis of crawl; tachograph; accelerometer; measuring methods for swimming

Introduction

In competitive swimming, there are many factors that influence swimmers' performance, such as physiological conditions, fitness, swimming technique and others. It is in the swimming technique that room can be found to improve and thus increase the prerequisites for overcoming one's personal record. Thanks to the constant shifting of World Records, the forthcoming Olympic Games, but also the efforts to shift the development and use of instrumentation in research and in the swimming training process, many research teams are trying to develop appropriate instrumentation revealing reserves or errors both in the swimming technique and in personal fitness.

Instrumentation can help to measure and analyze swimming techniques from multiple perspectives. At present, therefore, there are three directions of development of a measuring system for measuring the speed together with an analysis of swimming technique. Measurements of swimmers using video cameras and special software to measure the speed (Magalhaes, Sawaeha, Rocco, Cortesi, Gatta, Fantozzi, 2013), measurements of swimmers using accelerometers and speed measurement using devices on the principle of swimmer pulling a rope away from the measuring device, such as Swim speedo-meter (Intracyclic swim stroke velocity meter) (Barbosa, Morais, Silva and Batista Goncalves, 2011), and tachograph measuring system with a camera set from professor Motyčka, used by our team (the invention number 2012/179) (Motyčka, Šťastný,

[1] Brno University of Technology, Centre of Sports Activities, CZECH REPUBLIC
E-mail address: batorova@cesa.vutbr.cz
Received 21.03.2016 / Accepted 09.04.2016

[*] the abstract was published in the 16[th] I.S.C. "Perspectives in Physical Education and Sport" - Ovidius University of Constanta, May 20-21, 2016, Romania

Lepková, Pašek, Bátorová, 2013).

In our research facility at the Centre of sports activities, Brno University of Technology (CESA BUT) in addition to the development and improvement of existing tachograph measuring methods, together with synchronous underwater video recording of swimmers, we focus on the development of new measuring methods with accelerometers. Application of small inertial sensors enabled the discovery of new methods of swimmers motion analysis. These small systems are lightweight, easy to use and do not restrict swimmers during training, allowing easy monitoring, which after analysis leads to the improvement of training skills. Therefore, we decided at Brno University of Technology (BUT) to focus our further development of techniques in the measurement of swimmers in the aquatic environment to that direction. As the authors themselves stated, speed is a preferable parameter for the interpretation (Counsilman and Wasilak 1982). Analysis of swimming techniques using only acceleration is difficult and it is complicated to transfer to swimmers without deeper physical insight, so during our development of accelerometers methods, we focus on converting acceleration data into a graphical display of speed curve. Since 2015, our team in CESA BUT has worked in cooperation with the Faculty of Mechanical Engineering, the Department of Mechatronics and Robotics, to develop a measuring device with an accelerometer, which will be attached to the swimmer's back. There have been several hardware prototypes including hydrodynamic waterproof case. Our team is now working to develop software that would be able to display and plot the data, which would allow to analyze the technique based on the decrease in swimmer's speed in different axis. With this equipment, we should be able to evaluate also the turns and possibly starting jumps which has not been possible with the tachograph method so far. In further development, we will focus on synchronizing the graphic record of speed and acceleration with the camera system, to make the analysis of techniques as detailed as possible.

At present, for analysing swimming techniques in Czech top-level swimming, the most used measurement method is tachograph (Motyčka, Šťastný, Lepková, Pašek, 2010), which we have also used for our research measurement for this contribution. This device for measuring the speed of object linear motion or of a person with synchronous video recording has served for research measuring at BUT since 2009. Every year we perform measuring with the Czech national swimming team, swimming groups as well as swimmers from sports high schools. For the purposes of this paper, we selected only swimmers from the national swimming team, to ensure a similar level of performance and level of swimming techniques. Selection of swimmers for our qualitative research was intentional; swimmers with various techniques of crawl stroke and crawl kick were selected. We measured the depth and angles in crawl strokes both for arms and legs from video records, and compared this data with numerical expression of values calculated from the measured instantaneous speed measured by the tachograph (mean speed, efficiency, % of the maximum etc.).

The authors emphasize the importance of the length of the stroke and its effect on performance (Callaway, Cobb, Jones, 2009). This statement was also investigated by Chollet et al. (Chollet, Pelayo Delaplace, Tourny, 2011), who demonstrated a consistent ability of qualified swimmers to maintain a constant length of strokes throughout the race. However, in our research we focused not on the length of the swimming stroke, but the depth and angle and frequency; both for crawl arms and legs. Therefore we have set the following hypotheses for our front crawl research

H1: Swimmers with a deeper stroke have a higher mean speed.

H2: Swimmers with lower frequency of arm strokes have lower mean speed.

H3: Swimmers with a greater angle of stroke also have a higher mean speed.

H4: Swimmers with a deeper kick have lower mean speed.

H5: Swimmers with a deeper kick have lower efficiency.

H6: Swimmers with a higher frequency of kicks have a higher mean speed.

H7: Swimmers with a higher frequency of kicks have a higher leg efficiency.

Methods

For our biomechanical quantitative processing of front crawl arms and legs, we selected 6 men from the Czech national swimming team out of measurements made in 2012-2015; and for one of the swimmers we evaluated two measurements, so that we could compare his performance and changes in technique after one year. For our measurements, only men were selected from the Czech national swimming team, whose main swimming style is crawl. The swimmers were born in 1991-1994, with the exception of our best Czech swimmer who still actively raced at the time of measurement, and whose birth year is 1980. He was deliberately chosen for this research, so that we could compare his technique with other representatives. The swimmers were selected for their different techniques of crawl arms stroke. For our research, we measured separately crawl legs and crawl arms.

For measurements, we use the tachograph measuring system from professor Motyčka which consists of two measuring devices mounted with a special holder on the edges of the pool (Motyčka, Vlk, Krejsa, Ondrušek, Životský, 2009). The measuring device works based on optoelectronic rotary sensing of unwound flax rope, which is attached to the swimmers belt strapped at the level of the pelvic bones. Part of the measuring method is rear and front static underwater cameras and the side camera mounted on a moveable carriage. All the cameras are synchronized with each other and with the measuring device, therefore, it is possible to evaluate swimming techniques using a graphical display of speed and acceleration calculated along with video recording swimmers under the water surface.

For processing and evaluation of measured data we use SwimDataViewer sofware, which was created for this purpose, and is constantly under development to expand its additional options and features. From the instant speed of the swimmer, measured with the tachographs, the software calculates (at a specified interval) swimmer's maximum speed achieved in m/s, mean speed, dispersion values, standard deviation, coefficient of variation, what percentage of personal record the swimmer reaches in the measured section of the entire swimming style, and efficiency of the swimming technique of the measured swimmer. Efficiency of the swimming technique is calculated as the ratio of two works. The work, which the swimmer would perform if he/she swam uniformly, is always lower than the work at variable speed, and therefore the efficiency is always less than 1 (Motyčka, Šťastný, Lepková, Pašek, 2010).

$$\eta = \frac{\textit{work at uniform speed (lower)}}{\textit{work at real speed (higher)}} = \frac{k\bar{v}^3 t}{k\,\Delta t \sum_{i=1}^{n} v_i^3}$$

Measurements were carried out in a three-lane 25m swimming pool in Brno, which was reserved only for the measurement. During measurements, nobody except the measured swimmer was in the pool, to avoid distortion of measurements or underwater video record. Before the actual measurement, measured swimmers had 15 to 20 minutes for warm up exercise and swimming. Subsequently, they were informed about the organizational instructions for the measurement. The swimmers started at the sign of the operator and swam 50 meters of crawl legs and 50meters of crawl arms at maximum race speed. Between measurements, the swimmers swam 50 m slowly and had 3-5 minutes rest. For our purposes, we currently evaluated only the first 25 meters. For measuring of crawl legs, swimmers swam with a plate in anteriorly extended arms. For measuring of crawl arms, swimmers placed a pull buoy (leg float) between the thighs to provide support to the body without kicking their legs.

For measuring angles [°] and depth [px] of crawl legs and arms stroke from underwater video records, we used the MB-Ruler software (producer Markus Bader). We measured the angle at the elbow joint between the forearm and arm to the fingertips in the deepest stage of the shot. The depth of stroke was measured against the horizontal axis of the swimmer's body, along a perpendicular running to the tips of fingers/toes in the deepest stage of arms and legs stroke, respectively. The angle and depth of strokes were evaluated for each arm/leg separately and also as an arithmetic average of both arms/legs together. For measuring the angle and depth of crawl kick, a moving camera was used that recorded the side view of the swimmer. For measuring the angles of arm stroke, we used the front and rear stationary cameras and evaluated several strokes according to visibility, which could be affected by the amount of bubbles forming after swimmer's turn close to the rear camera, by swimmer's moving towards/away from the cameras, by water quality and light conditions during the measurement. For measuring the depth of crawl arm stroke, we used the side view camera that moves with the swimmer and is synchronous with the front and rear camera. When evaluating crawl arms and legs, we did not evaluate the first 2-3 seconds, because the values are affected by bouncing off the side; final strokes were not evaluated, either, where the swimmers already prepared for the touch.

For crawl legs and arms we evaluated personal maximum achieved in m/s in the evaluated interval, frequency of strokes and kicks, swimmer's mean speed, efficiency, number of kicks or strokes in the evaluated range, reached percentage of personal record for the 50meters freestyle achieved at the races. We also measured the angle of kick in the knee joint between the shin from the toe tips, and the thigh towards the hip. The interval for crawl legs evaluation was 3 - 13.5 seconds (10.5 seconds evaluated) and within the interval we took 21 kicks, where we measured the depth and angle of the kick; from the values we calculated the average depth of the kick and the angle for each leg separately as well as the average of both. For crawl arms, the first and last four to six strokes were taken to measure the angles, according to visibility enabling the measurement of angles from the video. From these values the average depth of stroke was also calculated, and the average angle of the arms in the deepest stage of the stroke. To evaluate average speed, efficiency, and other parameters of the crawl arms, we used the interval 2-10.5 seconds (8.5 seconds evaluated).

Underwater swimmers were recorded with Pixelink cameras with a maximum of 30 frames per second. We used a sampling frequency of 20 to 25 frames per second, and a notebook with 15.6 inches screen and a resolution of 1680x1050 pixels for measuring angles from video records. For data storing, processing and calculations, we used Excel and software Matlab (Producer MATLAB). To evaluate the measured data, we used mathematical method for fitting a set of points on a straight line (linear regression). To interpret the results, we used a graphical display of the results of the regression line and a description of the results. Using linear regression, we try to find the dependence of one set of values on the other.

Results

Linear regression was applied to dependence of mean speed on the depth of arm stroke (Figure 1). The result is a positive linear dependence

$$Mean\ speed = b_1 + b_2 \cdot depth\ of\ arm\ stroke$$

where $b_1=1.365$ and $b_2=0.001891$

However, the actual value of the mean speed may differ from this dependence. Given that the coefficients b_1 and b_2 are not equal to zero (the dependence of both sets would not be linear), but they are positive, the dependence can be considered a positive linear dependence. P-value was 0.0349 and is therefore lower than 0.05. We can therefore say that with the significance level of 5%, we have shown that the dependence of the two files is linearly positive (with increasing depth of stroke, the mean speed is increasing). The 95% confidence interval for the b_2 coefficient is (0.0001982, 0.003584). As the interval contains only positive values, it can be stated that dependence is positive. Since the lower limit of the interval is close to zero, the b_2 coefficient may not be estimated reliably, and the actual value may be near zero. This procedure we used also for further evaluation of results.

In Figure 1 we can see that the mean speed of a swimmer is directly proportional to the depth of stroke, which confirms our hypothesis 1 that swimmers with deeper crawl arms stroke have a higher speed than swimmers with smaller depth of stroke.

According to Figure 2, we can conclude that with increasing frequency the mean speed decreases, which means that the dependence is negative (inversely proportional). This may seem to disprove our hypothesis 2 that swimmers with lower frequency of strokes have a lower mean speed. However, this conclusion cannot be drawn because of the low number of swimmers measured; i.e. the result is statistically insignificant.

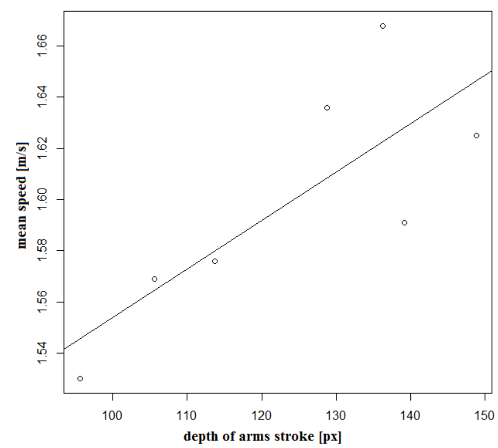

Figure 1. The dependence of mean speed on the depth of the crawl arms stroke

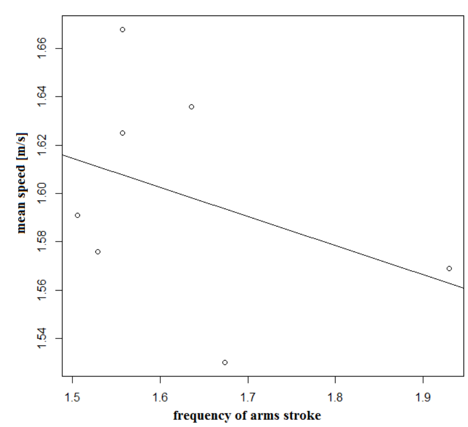

Figure 2. The dependence of mean speed on frequency of crawl arms

According to a graphical representation of values (Figure 3) it appears that the mean speed is directly proportional to the angle of arms stroke. From this we could conclude that hypothesis 3, in which we say that swimmers with a greater angle of the stroke also

Ovidius University Annals, Series Physical Education and Sport / SCIENCE, MOVEMENT AND HEALTH
Vol. XVI, ISSUE 2 Supplement, 2016, Romania
The journal is indexed in: Ebsco, SPORTDiscus, INDEX COPERNICUS JOURNAL MASTER LIST, DOAJ DIRECTORY OF OPEN ACCES JOURNALS, Caby, Gale Cengace Learning, Cabell's Directories

have a higher mean speed, is confirmed. However, also here, for a statistical significance of this assertion, it would be necessary to measure more swimmers.

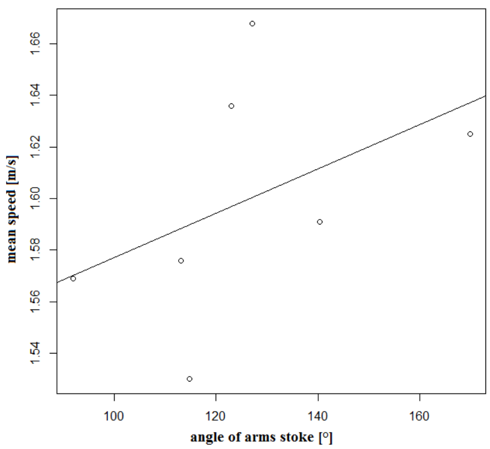

Figure 3. Dependence of mean speed on the angle of crawl arms stroke

In Figure 4 we can see that swimmers with a deeper kick have a higher mean speed, which disproves our hypothesis 4 that swimmers with a deeper kick have a lower mean speed. However, if we look at the chart from a qualitative point of view, it is obvious that the swimmer with the highest mean speed has a lower depth of kick. Therefore, it would be necessary to take more measurements for better verification of the hypothesis (like other hypotheses).

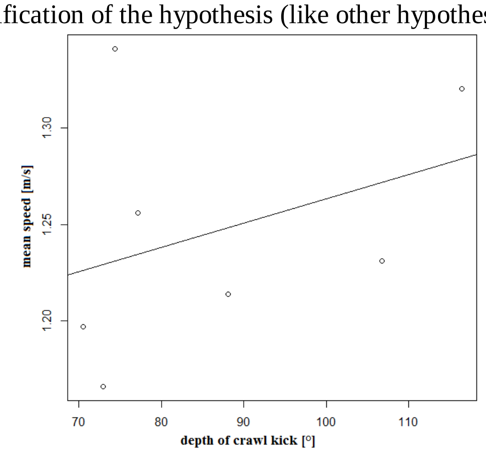

Figure 4. Dependence of mean speed on the depth of crawl kick

Our hypothesis 5, in which we say that swimmers with a deeper kick have lower efficiency, was not confirmed in Fig. 5a, as one of the measured swimmers has an extremely lower efficiency than the other swimmers. If we eliminate the extreme deflecting value (remove the value of swimmer K. J. with extremely low efficiency), our hypothesis 5 would be confirmed (Figure 5b) – that swimmers who kick deeper under water are less effective (due to higher speed fluctuations).

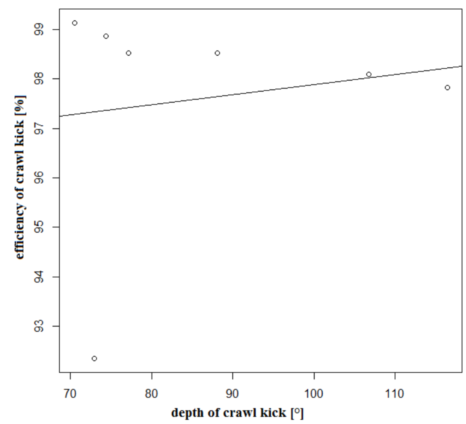

Figure 5a. Dependence of efficiency on the depth of crawl kick

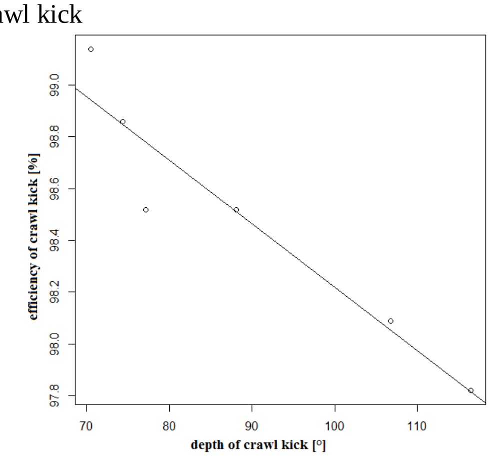

Figure 5b. Dependence of efficiency on the depth of crawl kick without the extremely deflecting value

Regression line with efficiency depending on the depth of crawl kick (Figure 5b), has the following factors b_1 = 100.7 and b_2 = -0.02459, which proves negative linear relationship. P-value is 0.00327. 95-percent confidence interval for coefficient b_2 is (-0.03545, -0.01373). It contains only negative numbers that are not as close to zero as in the previous case.

In Figure 6, we see that the dependence of mean speed on frequency is only slightly positive, and thus statistically nothing significant is shown. If we wanted to prove hypothesis 6 (that swimmers with a higher frequency of kicks have a higher mean speed) statistically, additional measurements would have to be done

Ovidius University Annals, Series Physical Education and Sport / SCIENCE, MOVEMENT AND HEALTH
Vol. XVI, ISSUE 2 Supplement, 2016, Romania
The journal is indexed in: Ebsco, SPORTDiscus, INDEX COPERNICUS JOURNAL MASTER LIST,
DOAJ DIRECTORY OF OPEN ACCES JOURNALS, Caby, Gale Cengace Learning, Cabell's Directories

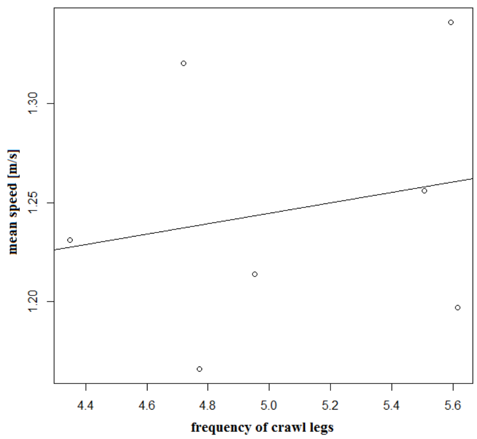

Figure 6. Dependence of mean speed on the frequency of crawl legs.

Hypothesis 7 in which we say that swimmers with a higher frequency of leg kicks have higher efficiency was confirmed but, thanks to swimmer K.J., who had significantly lower legs efficiency (92.34%) than all other swimmers, the dependence appears to be more positive (Figure 7a). If we remove the extremely deflecting value of swimmer K.J., the hypothesis is confirmed with much greater statistical significance.

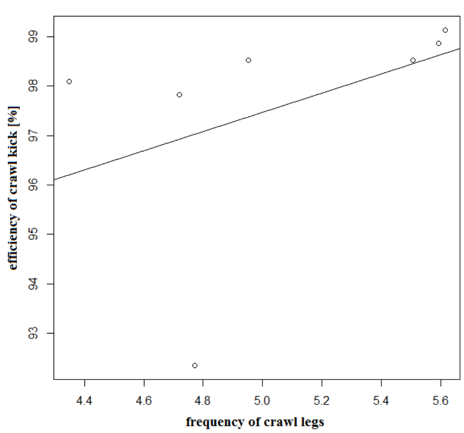

Figure 7a. Dependence of efficiency on frequency of crawl legs

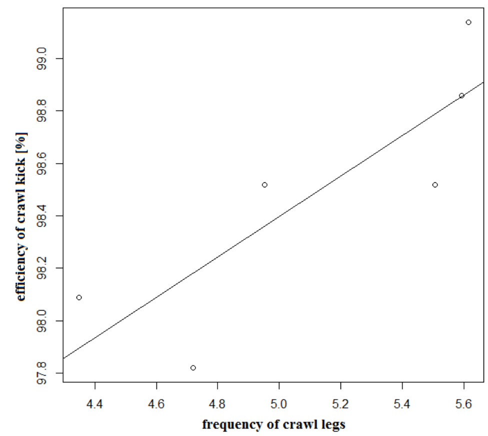

Figure 7b. Dependence of efficiency on frequency of crawl legs without the extremely deflecting value of swimmer K.J.

For dependence of effectiveness on leg frequency (Figure 7b), coefficients were determined $b_1 = 94.54$ and $b_2 = 0.7718$, which demonstrates positive linear relationship. P-value is 0.0348. 95-percent confidence interval for the coefficient b2 is (0.08952, 1.454). The coefficient may in fact be closer to zero, than was determined by estimation.

Discussion

According to the results of the crawl arms, we can say that the hypothesis 1 was confirmed, in which we say that swimmers with deeper arm stroke have higher mean speed. The subject to further investigation will be which depth of crawl arm stroke acts to increase the mean speed, and at what depth the stroke would have more likely negative effect. Our hypothesis 2, in which we say that decreasing frequency decreases the mean speed has not been proven. Subject of further investigation will be whether this hypothesis has not been confirmed only due to a small number of swimmers measured, or is actually negative. Hypothesis 3, in which we claim that swimmers with a larger angle of stroke have a higher mean speed, was confirmed but not convincingly, therefore the investigation for verification of this hypothesis will continue. However, if we look at the previous results, we can see that if the swimmers have a deeper stroke, they cannot have a smaller angle, or they wouldn't reach such a depth. It is therefore necessary to examine both hypotheses simultaneously on a larger number of swimmers.

For crawl legs, we set the hypothesis 4 that swimmers with a deeper kick have a lower mean speed. This hypothesis was not confirmed. On the contrary, the results show that swimmers with a deeper kick have a higher mean speed, so this hypothesis will be subject to further investigation. Hypothesis 5, claiming that the swimmers with a deeper kick have lower efficiency, has not been confirmed. A closer examination of the reason revealed that one swimmer with considerably lower legs efficiency significantly affected the results of both hypotheses 5 and 7 (hypothesis 7 also considers efficiency). We decided to test how the results would change if we omitted this swimmer for hypothesis 5 and 7, since even with hypothesis 7, this swimmer with significantly lower efficiency (large speed variations in the crawl legs technique) strongly affected the results. After removing the swimmer, hypothesis 5 was confirmed. Hypothesis 7, in which we claim that swimmers with higher frequency of kicks have greater efficiency of crawl legs was confirmed in both cases (including or excluding the swimmer with extremely deflecting efficiency). For hypothesis 6, dependence of the mean speed on the frequency is only slightly positive, and therefore statistically not proven.

Some interesting results show us the future direction of research and new research questions. Interesting results are shown in Figure 1, where we compare the depth of arm stroke and the mean speed. The results confirmed that the depth of arms stroke has an impact on the mean speed of swimmers. In further investigation, it is therefore necessary to focus on how deep the stroke (together with the angle of the arm) is the most appropriate for the maximum value of mean speed. The issue of appropriate crawl stroke according to the position of arms is also discussed by Maglischo (2003, pp. 105-108) and Verner (2009). Maglischo discusses three styles of transition phase in crawl, and indicates that the greatest angle of the arm is not suitable, but according to our results, the opposite is true. Verner in his thesis deals with both arm position in the stroke, and its depth with 3D analysis; however, he focused only on one swimmer and published no other results.

The results of comparison of the depth of the kick and frequency (Figure 4) show that swimmers with a deeper kick have higher mean speed. These results suggest a question, whether swimmers with deeper kick swim significantly faster (for verification, more measurements would have to be done) and, if so, whether it is advisable to swim with a deeper kick, and with a higher frequency. And whether swimmers are able to kick deeper and swim with high-frequency kick at the same time, which could increase their mean speed even further. Which raises further questions for exploring, whether this technique with a deeper kick in high frequency wouldn't be too energetically demanding for swimmers, or if the increased effort of the body and muscle groups wouldn't have rather negative impact on their overall swimming performance.

Conclusions

The presented research was conducted as a pilot study to outline the future direction of research and to verify the direction in which we want to continue the analysis of swimming techniques.

In our case-study contribution we presented the results of crawl technique measurements with the tachograph measuring method, where we focus on analyzing the crawl arms stroke and legs kick. In the results of our case study of 6 male swimmers from the Czech national swimming team, Hypothesis 1 was confirmed (swimmers with a deeper arm stroke have a higher mean speed). Hypothesis 2 (mean speed is decreasing with decreasing frequency) was not confirmed. Hypothesis 3 (swimmers with a greater angle of arm stroke also have a higher mean speed) was confirmed. Hypothesis 4 (swimmers with a deeper kick have lower mean speed) was not confirmed. Hypothesis 5 (swimmers with a deeper kick have lower efficiency) was not confirmed. For Hypothesis 6, the dependence of mean speed on the frequency was only slightly positive, and thus statistically insignificant. Hypothesis 7 (swimmers with higher frequency of kicks have higher efficiency of crawl legs) was confirmed.

We would like to further investigate our hypotheses with a higher number of swimmers, because we believe that confirming or disproving our hypotheses could be of great importance in further development of research in swimming techniques analysis and swimming training preparation of the Czech national team.

Aknowledgements

For all of our participants from my study I want to say thank you.

References

Barbosa T, Costa M, Morais J, Jesus S, Silva A, Batista J, Goncalves J, 2011, Validation with videometry of an integrated system to assess horizontal intra-cyclic velocity with a mechanical speedo-meter. pp. 833-835. Retrieved from: https://bibliotecadigital.ipb.pt/bitstream/10198/6117/1/Biomechanics%20in%20Sports%2029%20-%20speedo%20meter%20validation.pdf.

Callaway AJ, Cobb JE, Jones I, 2009, A Comparison of Video and Accelerometer Based Approaches Applied to Performance Monitoring

Chollet D, Pelayo P, Delaplace C, Tourny C, Sidney M, 2011, Stroking Characteristic Variations in the 100-m Freestyle for Male Swimmers of Differing Skill, Perceptual and Motor Skills, 85(1), pp. 167-77. In Swimming. International Journal of Sports Science and Coaching, 4 (1), 139-153.

Counsilman JE, Wasilak J, 1982, The Importance of Hand Speed and Hand Acceleration. In: R.M. Ousley. Ed. ASCA World Clinic Yearbook, pp. 41-55. Fort Lauderdale: American Swimming Coaches Association.

Frantová M, 2010, Power distribution by swimming style crawl [Diploma thesis]. Brno: Masaryk University.

Magalhaes FA, Sawaeha Z, Rocco DM, Cortesi M, Gatta G, Fantozzi S, 2013, Effectiveness of an Automatic Tracking Software in Underwater Motion Analysis. Journal of Sports Science and Medicine, Vol. 12, pp. 660-667.

Maglischo EW, 2003, Swimming Faster. 105-108 Champaign: Human Kinetics.

Motyčka J, Šťastný J, Lepková H, Pašek M, Bátorová M, 2013, Kinematic and dynamic analysis of swimmnig 2009 – 2013. In Sport and quality of life 2013. Brno: Masaryk University.

Motyčka J, Šťastný J, Lepková H, Pašek M, 2010, Dynamická a kinetická analýza techniky plavání reprezentace ČR 2009/2010, In Optimální působení tělesné zátěže. pp. 84-90. Hradec Králové: UHK.

Motyčka J, Vlk M, Krejsa J, Ondrušek V, Životský Z, 2009, Analýza výsledků měření rychlosti plavání se synchronizováním videozáznamu pod vodou. In *Sport and Quality of life 2009.* Brno: Masaryk University.

Verner M, 2009, Analysis of a sprint swimmer technique, [Diploma thesis]. Brno: Masaryk University