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The kinematic analysis of 3 repeated 200 meters freestyle swimming performances of swimmers aged 13-15 years

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Abstract

The aim of this study is to investigate the differences in kinematic parameters of freestyle swimming with respect to young swimmers before and after 3x200 metres (m) performances. Seven male swimmers (mean age: 13.86±0.90; mean height: 164.79±6.89cm; mean mass: 54±5.54kg) participated in this study as volunteers without any injury history. Before the test, the cube calibration was used to calibrate the field for calculation of kinematic parameters. Also, appropriate warming time was given to all participants and then, reflector markers were attached to their selected joints. When the swimmers were ready, they were asked to perform 3x200m freestyle, and their performances were recorded by three underwater cameras (60hz). Stroke length, stroke rate, stroke count, and end time were calculated as performance parameters, while the values of segmental angles were calculated as kinematic parameters using SIMI Motion, version 8.7.2. The differences between the beginning of the first 200m and end of the third 200m performances with respect to kinematic parameters were identified using Wilcoxon Test in SPSS 18.0 (SPSS Inc., Chicago, IL, USA) program. Also, the relationships between performance parameters and kinematic parameters were assessed using Pearson Correlation Cofficient. The results of this study indicate that there is a positive relationship between elbow angle and stroke count (r=.946). Also, there is a negative relationship between stroke length (r=-.934) and stroke rate (r=-.867) at the pull phase, while there are significant relationships between wrist angle, velocity (r=-.838) and end time (r=.824) at the push phase (p<0.05).

Keywords: Biomechanics; Freestyle; Swimming; Kinematic analysis

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1. Introduction

1.1. Introduce the problem

Swimming is characterized by a sequence of coordinated actions of the trunk and limbs in a repeated, synchronous pattern (Mooney et al., 2016). Front crawl is the fastest form of human locomotion in an aquatic environment. The world records in freestyle events, in which most swimmers, if not all, use the front crawl technique, demonstrate the level of sophistication of the skill of human locomotion in water (Yanai, 2003). In order to study human mobility in the aquatic environment, underwater analysis of swimmers is required. Previous studies that examined the active movements of swimmers involved in freestyle swimming categorized them into three phases: entry and catch, pull, and push (Chollet, Chalies & Chatard, 2000; McCabe and Sanders, 2012). Nowadays, swimming is broken down into different segments to facilitate technical analysis and the selection of different categories of performance related variables for measurement purpose. The main groups are performance, kinematic and kinetic. Also, four properties are analyzed in performance parameters: stroke length, stroke rate, swim velocity, and acceleration (Mooney et al., 2016; Zamparo et al., 2009; Schnitzler et al., 2010; Formosa, Mason & Burkett, 2011; Figueiredo et al., 2013).

In previous research, the freestyle technique was studied in three dimensions. The results of these studies indicate that there is a positive relationship between swim velocity and stroke rate. However, there is a negative relationship between stroke rate and stroke length (Chollet, Chalies & Chatard, 2000; Craig et al., 1985; Hellard et al., 2018). Psycharakis and Sanders examined the shoulders of swimming men (n=10 males) involved in 200m freestyle. They found that faster swimmers tend to roll their shoulders less than slower swimmers and the average shoulder angle of the athletes was calculated as 106.6±8.4° (Psycharakis & Sanders, 2008). It was emphasized that the freestyle elbow angle may not be 90° (Cappaert, Pease & Troup, 1995). Payton et al. found that the angle of the elbow was 105°. On average, elbow flexion accounted for 25% of the hand velocity in the middle of the insweep (Payton, Baltzopoulos & Bartlett, 2002). Different values of elbow angles were obtained at each phases (Figueiredo et al., 2013; Payton, Baltzopoulos & Bartlett, 2002; Schleihauf, 1988). Caty et al. investigated the angle of the wrist in freestyle swimming involving 7 male senior athletes. The calculated wrist angles of the swimmers were between 174.03° and 198.43° (Caty et al., 2007). There was no significant difference between the values of the kinematic and performance parameters at the pull and push phases (McCabe and Sanders, 2012; Gourgoulis et al., 2014).

After reviewing the above previous studies, we observed a missing link with respect to the relationship between kinematic and performance parameters in swimming. Therefore, the aim of this study is to evaluate the upper body angles during the active phases of freestyle swimming with regards to well-trained male subjects. Sportsmen and coaches have employed many analytical techniques with respect to freestyle swimming. The specific techniques that the athlete applies in water and the application of these techniques are investigated in this research. The technical change in force application in water by an athlete is an important factor affecting athletes' performance. For this reason, the kinematic parameters of male swimmers performing three repetitive 200m freestyle are the analysed and the changes in the active technique in water are examined.

2. Method

2.1. Participants

Seven male swimmers (mean age 13.86±0.90yrs; mean height 164.79±6.89cm; mean weight 54±5.54kg; training experience 6.57±0.72yrs) from Istanbul Technical University Sport Club participated in this study voluntarily. The swimmers had not experienced any upper and lower extremity injuries at the time of participation. The study was conducted in accordance with the recommendations of the Declaration of Helsinki. Before participating in the study, swimmers were informed of the potential risks and benefits, and they provided written informed consent to participate, in accordance with the policies and procedures of the University of Halic's Human Research Ethics Committee regarding the use of human subjects in research (Ethical clearance number: 21). The swimmers were asked to refrain from caffeine intake on the test day and avoid food consumption 2 hours before testing.

2.2. Data collection tool

The data collection was done in Istanbul Technical University Swimming Hall, Istanbul. Tests were carried out during off-season for the preparation of competition strategy. The subjects had 14-hour training session per week. Before the tests, 15 minutes warm up time was given, followed by 5 minutes dynamic strechings in dry land and 10 minutes free swim in the swimming pool.

Reflector markers of 3cm diameter were attached to selected joints of participants in the right upper extremity, such as right acromion, olecranon, medial styloid, digitus mediun and great trochanter. These markers were applied to the participants with double-sided tape.

Kinematic data were collected using three (60hz) SJ4000 under water cameras, which were syncronized using SIMI Motion Track Manager. The cameras were placed at a distance of 4-6 meters from each other, as shown in Figure 1. For field calibration, direct linear transformation technique was used, developed by Abdel-Aziz and Karara (1971) and Shapiro (1978) (Abdel-Aziz & Karara, 1971; Shapiro, 1978). Eight calibration points were calculated using 30cm x 30cm x 50cm calibration cage (Figure 2). Marker trajectories were low pass filtered at 5Hz using Butterworth filter. Swimmers performed three repetitions of 200m freestyle swimming after warm-up, and different swimming positions of the performances were recorded, which consisted of entry and catching phase, pull phase, and push phase. For every phase, the joint angles of the right upper extremity (wrist, elbow and shoulder) were assessed to examine the differences between the beginning of the first 200m and the end of the third 200m. For analyses of the 3D angular kinematics, SIMI Motion Reality Software, Version 8.7.2, was used.

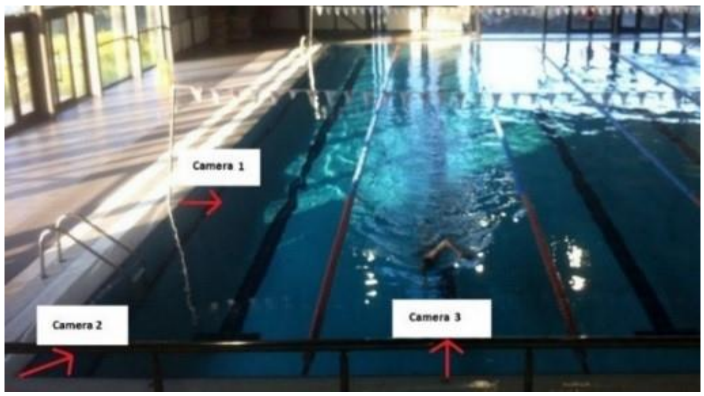

Figure 1. Camera Positions

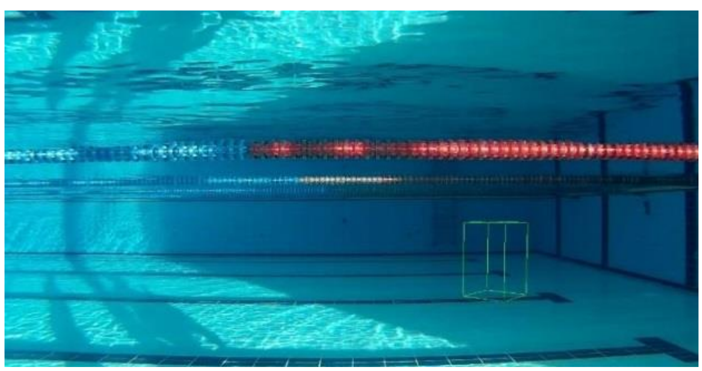

Figure 2. Field Calibration View

Additionally, the following performance parameters of the 200m freestyle swimming were recorded by Casio HS-70W-1DF stopwatch as;

- Stroke count (SC),
- Stroke lenght (SL) (with formula of Distance/SC),
- Stroke rate (SR),
- End time (ET)
- Total velocity (TV) (with formula of Distance/Total time).

2.3. Data Analysis

The data of angular kinematic variables from swimming trials were statistically analysed using SPSS 18.0 (SPSS Inc., Chicago, IL, USA) program. The results are presented as means±SD. Wilcoxon test was utilized to identify any differences between the beginning of the first 200m and the end of the third 200m. Also, Pearson Correlation analysis was used to evaluate the relationship between the performance parameters and angular kinematic parameters. The statistical significance level was set at 0.05.

3. Results

The evaluated performance parameters of the three repetitions of 200m are shown in Table 1. According to the results, total SC, total SR, total SL, end time and total velocity were found as 175.33±12.11times, 5.86±0.51s, 4.04±0.28m/stroke count, 151.15±6.56s and 1.33±0.06m/s respectively. No significant differences were found in the phases between the beginning of the first 200m and the end of the third 200m regarding the shoulder, elbow and wrist angles ($p<0.05$) (Table 2). In the first 200m at the pull phase, there was a significant positive relationship between elbow angle and SC (R=.946; .799) and a negative relationship between elbow angle and SL (R=-.934; -.800). In addition, there was a negative correlation between $SR_{initial}$ and elbow angle (R=-.867). When the angle of the wrist was examined, the TV was found to be negative (R=-.838) and the ET was positive (R=.824) (Table 3).

Table 1. 3x200m Performance Parameters of Swimmers as Mean±SD

Performance Parameters	1st 200m	2nd 200m	3rd 200m	Total
SC1 (50m)	40.57±2.76	42.71±2.69	42.71±2.43	42.00±2.70
SC2 (50m)	43.00±3.21	43.71±3.25	44.29±1.98	43.67±2.78
SC3 (50m)	43.14±2.67	45.00±3.87	45.00±3.92	44.38±3.47
SC4 (50m)	44.57±3.31	46.00±4.73	45.29±3.35	45.29±3.70
Total SC (200m)	171.29±11.48	177.43±14.21	177.29±11.22	175.33±12.11
$SR_{initial}$ (s)	2.81±0.21	2.97±0.38	2.73±0.39	2.84±0.33
SR_{final} (s)	3.20±0.26	2.99±0.20	2.89±0.16	3.03±0.24
Total SR (s)	6.01±0.44	5.95±0.52	5.63±0.54	5.86±0.51
SL1 (m/SC)	1.09±0.07	1.03±0.07	1.03±0.06	1.05±0.07
SL2 (m/SC)	1.03±0.08	1.01±0.07	1.00±0.04	1.01±0.07
SL3 (m/SC)	1.02±0.06	0.98±0.08	0.98±0.08	1.00±0.07
SL4 (m/SC)	0.99±0.08	0.96±0.09	0.98±0.07	0.98±0.08
Total SL (m/SC)	4.13±0.28	3.99±0.31	3.99±0.25	4.04±0.28
End Time (s)	151.61±6.08	151.47±7.03	150.36±7.48	151.15±6.56
Total Velocity (m/s)	1.33±0.05	1.33±0.06	1.34±0.07	1.33±0.06

Table 2. The Differences Between the Angular Parameters of the Initial and Final 200m for Different Phases

		200m initial Mean±SD	200m final Mean±SD	P value
Entry and Catch	Shoulder Angle (°)	153.86±12.60	155.82±8.32	0.49
	Elbow Angle (°)	153.11±12.79	159.72±8.49	0.31
	Wrist Angle (°)	153.47±13.20	153.77±12.92	0.86
Pull Phase	Shoulder Angle (°)	90.54±40.73	90.47±38.89	0.86
	Elbow Angle (°)	96.72±13.13	92.47±15.82	0.49
	Wrist Angle (°)	167.42±6.45	166.26±9.05	0.49
Push Phase	Shoulder Angle (°)	50.97±54.33	51.13±49.22	1.00
	Elbow Angle (°)	101.96±37.71	102.88±40.91	1.00
	Wrist Angle (°)	163.68±13.63	163.47±14.98	1.00

$p>0.05$

Table 3. The Relationship Between the Performance and Kinematic Parameters

	Elbow 1st 200m Pull Phase	Wrist 1st 200m Push Phase
1st 200m SC	.946**	-
3rd 200m SC	.799*	-
1st 200m $SR_{initial}$	-.867*	-
1st 200m SL	-.934**	-
3rd 200m SL	-.800*	-
1st 200m TV	-	-.838*
1st 200m ET	-	.824*

*$p<0.05$ **$p<0.01$

4. Discussion

A number of studies have been conducted around the world on the relationship between the performance characteristics of athletes and their relationship with pull mechanics in freestyle swimming (Cappaert, Pease & Troup, 1995; Laffite et al., 2004; Seifert, Chollet & Chatard, 2007). For analysis purpose, swimming parameters are divided into performance, kinematics and kinetics. Performance parameters include the speed of the athlete, the number of strokes, the stroke frequency, the stroke length, the lap times, and the end time. Kinematic parameters are linear velocity, acceleration, displacement, angle, angular velocity, and angular acceleration of any segment of an athlete (Mooney et al., 2016). In previous studies, two- and three-dimensional analyses were carried out by videography of underwater kinematics. In our study, we conducted underwater analysis of the push mechanism. In this study, the relationship between performance and kinematic parameters of the athletes were determined. In addition, the initial and final kinematic parameters of the athletes were compared.

In general, there are limitations to laboratory work. First of all, it is sometimes impossible to fully provide the race environment, no matter how convenient the conditions are. This is especially true for the aquatic environment. Secondly, laboratory evaluations are usually based on physiology and basic motoric properties and are less suitable for biomechanical studies. High performance pools are also available for swimming, and video analysis and measurements are usually performed there. Individual analysis of images taken are performed. The performance of the cameras during the monitoring is important. Biomechanics is a detailed part of the performance analysis and uses direct and indirect measurement methods to measure the movement of the swimmers. Physiological investigations specifically examine energy systems in the athlete's training, racing and resting process (James, Burkett & Thiel, 2011).

Swimming is characterized by repeated and timely movement of the torso and hips. Arm movement is different in all four racing styles, and each style includes its own traction phases. The video imaging system has both advantages and disadvantages in the aqueous environment: hidden body segment and water turbulence. Digitizing values and analyzing data in video analysis is an intense and time-consuming task that is labor intensive. Nonetheless, based on the results of the survey on swimming, coaches found that quantitative analysis in the natural environment is very important (Mooney et al., 2016).

Three-dimensional analysis of the surface has been conducted according to the coordinates (Berger, 1999). Ceseracciu et al. used SIMI (Reality Motion Systems GmbH) (Ceseracciu et al., 2011). The freestyle mechanism was studied in three dimensions. Psycharakis and Sanders examined the shoulders of males (n=10) in 200m freestyle swimming. The average shoulder angle of the athletes was calculated as 106.6±8.4° (Psycharakis & Sanders, 2008). In this study, the shoulder angles at the first and last 200m were 98.46° and 99.14° respectively.

Caty et al. investigated the wrist angles of 7 male senior athletes during freestyle swimming. The wrist angles of the athletes were examined individually. The results of the study indicated a wrist angle of 183.38° for the first athlete, 198.43° for the second athlete, 174.03° for the third athlete, 198.30° for the fourth athlete, 190.79° for the fifth athlete, 189.63° for the sixth athlete, and 179.05° for the seventh athlete (Caty et al., 2007). In this study, the wrist angles were respectively 168.81°, 162.85°, 175.77°, 158.67°, 171.36°, 161.54°, and 172.92°. The wrist angles of the athletes were calculated between 128.92° and 178.34° when examined according to the phases throughout the study.

Schleihauf worked with 14 male 12 female senior athletes in 1984. The kinematic values of the four swimming styles were examined in the study, and the elbow angle of the subject group for freestyle was found to be 93±11° (Schleihauf, 1988). Another study involved five athletes participating in 200m swimming and below and four athletes participating in 200m swimming and above. In the study, the elbow angle was found to be 106.5° (Cappaert, Pease & Troup, 1995). In this study, it was emphasized that the elbow angle of freestyle may not be 90°. Payton et al. found that the elbow angle was 105° (Payton, Baltzopoulos & Bartlett, 2002). Another study investigating the elbow angle change in freestyle active motion was conducted with 10 male athletes (mean age 21.6±2.4yrs). In the study, the elbow angles of the athletes were calculated at the beginning and end of the 200m swimming. Figueiredo et al. found that the elbow angles at the beginning and end were 149.7±11.2° and 149.0±8.1° at the entry phase, 102.2±13.4° and 95.9±10.7° at the pull phase, as well as 143.0±3.3° and 136.3±4.8° at the push phase. The elbow angle difference was calculated as 47.6±14.7° for the pull phase and 40.8±14.9° for the push phase (Figueiredo et al., 2013). In this study, the elbow angle at the beginning and end of the 200m swimming was 150.46±11.70° and 157.53±6.81° at the entry and catch phase, 99.56±11.80° and 91.71±17.19° at the pull phase, as well as 114.75±18.26° and 103.51±44.77° at the push phase, which is in parallel with literature.

McCabe and Sanders compared the kinematic parameters of sprinters with those of long-distance athletes in their study. In the study, the elbow, wrist and toe angles were examined. There was no significant difference between the angles for the two groups ($p>0.05$) (McCabe and Sanders, 2012). In another study, Gourgoulis et al. examined both active and passive movements of strokes. There was no significant difference between the kinematic and performance parameters in the pull and push phases ($p>0.05$) (Gourgoulis et al., 2014). In this study, it was found that there was a positive relationship between elbow angle and stroke count ($r=.946$; .799); however, there was a negative relationship between elbow angle and stroke length ($r=-.934$; -.800) in the first 200m pull phase. In addition, there was a negative correlation between initial stroke rate and elbow angle ($r=-.867$). When the wrist angle was examined, there was a negative relationship between total velocity and wrist angle ($r=-.838$); however, there was a positive relationship between end time and wrist angle ($r=.824$) in the first 200m push phase. This could be due to the difference in race distance and styles of our subject group.

5. Conclusions

There was a significant relationship between the angle values of the elbow and wrist and some performance characteristics ($p<0.05$). Knowing the wrist and elbow angles individually and training them with the right angles in both land and pool training is one of the determining factors of performance and special training models should be applied to the athletes in this regard. In the 3x200m swimming test, there was no change in the kinematic parameters of this age group. Since it is not possible to perform analysis in the competition environment due to the limitations in kinematic analysis in swimming sports, the use of video technologies without markers is suggested for analysis. Also, the investigation of kinematic parameters with respect to comparing different groups and gender is suggested. It is considered that optimal performance grades can be achieved by considering some kinematic parameters in the athletes of this age group. Athletes should be evaluated separately according to their age groups and training should be done by adhering to specific developments. Training designs should be created according to the amateur or professional status of the athletes. The camera positions should be determined. Video images should be taken into account during the training and education should be given by watching with the athletes. This study will contribute to the preparation of training programs for professional swimmers in our country and to the determination of appropriate race techniques.

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