Journal of Physical Education and Sport ® (JPES), Vol.20 (5), Art 346, pp. 2539 - 2544, 2020
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

The influence of short-term training volume increase on biomechanical variables in age-group swimmers

GRZEGORZ BIELEC[1], PIOTR MAKAR[2], RICARDO FERNANDES[3]
[1]Department of Tourism, Recreation, and Ecology, University of Warmia and Mazury, Olsztyn, POLAND
[2]Faculty of Physical Culture, University School of Physical Education and Sport, Gdansk, POLAND
[3]Centre of Research, Education, Innovation and Intervention in Sport, University of Porto, PORTUGAL

Published online: September 30, 2020
(Accepted for publication: September 22, 2020)
DOI:10.7752/jpes.2020.05346

Abstract
Problem statement. Biomechanical factors influencing swimming performance in age-group athletes have been presented in scientific literature in recent years. Frequent analysis of swimming biomechanics is a means of controlling the training loads used in successive phases of the macrocycle. Literature provides information about changes in kinematics caused by reduction of training volume whereas data concerning effects of increasing training volume are rare. The aim of the study was to assess the effects of a seven-day conditioning camp with increased training volume to biomechanical variables of 400 m freestyle performance among age-group swimmers. *Methods.* Ten female and ten male swimmers aged 12-13 years participated in a seven-day camp, where training volume was increased by 30% compared to pre-camp weeks. Basic anthropometric measurements were taken during the camp and eight days afterwards. Young athletes performed three 400 m freestyle trials at the beginning of the camp, at the end of the camp, and eight days after the camp during the competition. The performance was video-recorded and biomechanical variables were calculated with Stroke Mechanics Test. *Results.* Stroke rate, stroke length and stroke index values increased slightly during the study period ($p>0.05$). Swimming speed increased substantially from the beginning of the camp to the competition ($p<0.05$). Stroke index was strongly correlated with swimming speed in all dates of performance ($r>0.71$, $p<0.05$). Stroke rate did not show significant correlations with swimming speed, whereas stroke length was associated with performance time during competition. *Conclusions.* Short-term increase of training volume in camp conditions may be beneficial in improvement of swimming technique and increase the swimming speed among age-group swimmers.
Keywords: swimming biomechanics, adolescents training, stroke index, stroke rate, stroke length

Introduction

The analysis of factors influencing swimming performance is not carried out only in adult athletes, but more and more often concerns adolescents and even children. In young swimmers, substantial relationships were found between anthropometric variables (e.g. body height, arm span, and limb length) and athletic performance (Nevill, Oxford, & Duncan, 2015). Body composition, especially the adipose tissue percentage, also show relationships with performance in teenage swimmers (De Mello & Bohme, 2010). The anthropometric parameters changing rapidly during puberty influence the technical structure of adolescent swimmers movement. Complementarily, it is well accepted that the assessment of the swimming technique's effectiveness is usually based on the biomechanical factors: speed (v), stroke rate (SR) and stroke length (SL). Periodical analysis of kinematics variables in age-group athletes is recommended in order to broaden knowledge of training process (Tucher et al., 2019). It was found that the swimming technique of children and adolescents at puberty is characterized by a higher stroke rate and a lower stroke length compared to adults (Zamparo, 2006). Another study indicated that higher speed over a distance of 50 m freestyle was achieved by teenage athletes with a higher stroke length (Toskic, Lilic, & Toskic, 2016).

The stroke index is the product of swimming speed and the stroke length. This variable is frequently used for the assessment of swimming technique in children and adolescents since it best reflects the level of effectiveness of an individual technique. Strong negative correlation between the stroke index and the energy cost of swimming was discovered in adult athletes decades ago (Costill et al., 1985). In teenage swimmers, the substantial links were found between the stroke index and the propelling efficiency of 400m freestyle performance (Longo et al., 2008). Stroke index values were also correlated with blood lactate concentration in 4x50-m front-crawl test performed by teenage swimmers (Tucher et al., 2018). Moreover, other findings indicate that among many anthropometric, energetic and biomechanical variables analyzed in early pubescent swimmers, palm width and stroke index proved to be the most significant determinants of 25-m front crawl performance

Corresponding Author: GRZEGORZ BIELEC, E-mail: grzegorz.bielec@uwm.edu.pl

(Figueiredo et al., 2016). Similarly, the value of the stroke index appears to be the most decisive factor determining the results of 100 m freestyle in adolescents aged 15 years (Latt et al., 2010). The authors of the abovementioned studies advise the development of the swimming technique of children and adolescents in terms of increasing the stroke length while maintaining constant speed, which guarantees an improvement in sports results. Some data indicates that training loads used in age-swimmers affect changes in biomechanical variables. Analysis of the 15-week mesocycle in juvenile swimmers displayed substantial correlations between the stroke rate and the 100-m individual medley speed (Kucia-Czyszczon et al., 2013). On the other hand, no distinct changes in the biomechanical variables of 400-m freestyle performance were found after the reduction of training loads during the taper period (Toubekis et al., 2013).

Training season in age-group athletes is usually connected with the school-year. It starts in August-September and finishes in June-July, depending on the country or region. Training season is divided into 2-4 macrocycles determined by targeted competition. Each macrocycle consists of preparation phase, specific phase, taper and performance phase, and, finally transition phase. Training loads, i.e. volume, intensity and recovery are planned according to the demands of current phase of macrocycle. Although training patterns can be found in literature, they refer to adult athletes (Hellard et al., 2019). Recently the tendency of reduction the training volume (so-called "mileage") and increase of training intensity at the same time is described in literature (Chatard & Stewart, 2011). On the other hand, the need of building the aerobic base in age-group swimmers is also highlighted (Nugent et al., 2017). There are some studies describing changes in swimming kinematics of youth athletes affected by decreased training volume or detraining period (Zacca et al., 2019). To our knowledge, there are no studies presenting biomechanical analysis of swimming performance under conditions of rapidly increased training volume among juvenile swimmers.

The aim of this study was twofold:

(i) to assess the effectiveness of applying the increased training volume for 6 days on the results of 400m freestyle performance, and (ii) to evaluate changes in the stroke index and other biomechanical variables due to increased training volume. We hypothesized that short-term increase of training loads would affect changes in biomechanical variables of middle-distance swimming performance.

Material & methods

Participants

The study group consisted of twenty swimmers (including ten girls) aged 12.6 ± 0.4 years, who have been regularly trained for three years. During the last 5 weeks before the camp, in the preparation phase, the athletes spent on average three hours a day on training (2x90 min sessions), five days a week. In this phase the volume of the training unit was on average 3.8 km ± 0.6 per day. The participants of the experiment gave their consent in writing. Written consent was also provided by the parents of the children. The local Ethics Committee has approved this experiment in accordance with the Helsinki Declaration.

Procedures

Swimmers participated in a seven-day training camp, which main task was to improve the participants' aerobic abilities. The camp took place in the specific phase of the macrocycle, which is characterized by high training volume with moderate intensities. The main competition was to take place 6 weeks after the camp. During the camp week, the participants had four hours of swim training a day (2x120 min sessions) with average volume of 5.5 km ± 0.3 per session. The difference in training unit volume during and before the camp was 30.1 % and was statistically significant (p<0.01). Before the camp, children were asked to self-assess their biological development according to the Tanner scale (Roberts, 2016). The self-assessment was done at the participants' home, under the supervision of their parents. On the first day of the camp the participants' body height was measured with the Seca 711 stadiometer (Seca GmbH, Germany) while body weight, body mass index and fat percentage with the Tanita BC 545 N analyzer (Tanita Corp. Japan). Each measurement was taken twice by an experienced nurse. For each pair of measurements a coefficient of variation was calculated, the values of which ranged from 2.3 to 3.0 (Table 1).

Table 1. Mean value and standard deviation of anthropometric variables of examined swimmers

	body height (cm)	body mass (kg)	body mass index (kg/m^2)	body fat (%)	maturation stage (Tanner scale)
Girls (n=10)	160.2±9.2	50.8±9.7	19.6±1.8	22.8±3.1	2.2±0.6
Boys (n=10)	159.6±6.5	46.7±9.8	18.3±3.4	16.3±5.1	2.0±0.4

On the second day of the camp, the first swimming test (Trial 1) was conducted. After standard 600-m warm up in the water, the athletes performed 400m freestyle according to FINA regulations. The test took place on a six-lane 25-metre swimming pool. Water temperature was 27 degrees Celsius and air temperature 28 degrees Celsius. The time of each participant's performance was measured by a competent referee using two Casio HS 80 TW stopwatches.

To assess the swimming technique Stroke Mechanics Test adapted to the conditions of a 25-metre swimming pool was used (Pyne, Maw, & Goldsmith, 2000). The swimmers' performance was recorded with a

Sony Hi-8 camera (25 Hz) in the zone between the fifth and twentieth meter of the swimming pool. Five full strokes were recorded on each pool length passed by the participant. Based on the recorded movie the following variables were calculated (Bielec & Makar, 2010):

Stroke Rate (SR) = 60 x 5/ tSR (time of 5 cycles)

Speed (v) = S (distance) / t (time)

Stroke Length (SL) = v x 60 / SR

Stroke Index (SI) = v x SL

Due to the fact that the athletes started the performance from starting blocks, the biomechanical analysis did not include the measurements made on the first 25-metre section. On the seventh day of the camp the second test (Trial 2) was carried out on 400 m freestyle under previously described conditions. Eight days after the end of the camp all participants took part in a local swimming competition, where they performed 400 m freestyle.

The competition took place in a swimming pool with very similar characteristics to the facility used during the camp, i.e. a 25-metre pool with six lanes, water and air temperatures of 27 and 27 degrees Celsius respectively. Time was measured by hand by experienced judges using two stopwatches. On the day of the competition, before the start, body height, body weight, fat percentage and BMI were measured. No significant differences were found compared to the measurements taken on the first day of the camp.

Based on the studies indicating that in early pubertal children gender does not affect changes in physiological and biomechanical parameters, the results of girls and boys in this study were analyzed jointly (Moreira et al., 2014).

Statistical analysis

The statistical analysis was based on Statistica 12.0 (StatSoft, USA). The data distribution was normal according to the Kruskal-Wallis test. Differences in the values of analyzed parameters were evaluated using ANOVA variance analysis and Tukey's post-hoc test. The correlation coefficient was used to assess the relationship between swimming speed and biomechanical parameters. The homogeneity of the variances of the variables tested was determined by the Levene test. Statistical significance was assumed at the level $p<0.05$.

Results

The values of stroke length, stroke rate and stroke index increased slightly after seven days of the conditioning camp (Table 2). Another increase in the examined parameters was observed after another 8 days, when the athletes were already training in local conditions. The variance analysis did not show any significant changes in these variables. More distinct variations were noted in swimming speed and time of covering 400 m freestyle. The application of increased training volume during the camp resulted in an increase in average swimming speed (1.15 ± 0.09 m/s vs. 1.18 ± 0.08 m/s, p=0.64). The average swimming speed, which was achieved in the competition 8 days after the camp was even higher (1.22 ± 0.08 m/s, p=0.21). The post-hoc test revealed statistical significance of the difference in swimming speed recorded at the beginning of the camp and during the competition (p=0.03). Mean time of covering 400 m freestyle decreased distinctly. At the beginning of the camp the average time achieved by the participants was 348.2 ± 28.55 s, while at the end of the camp 340.6 ± 26.18 s (p=0.62). During the competition the average time of covering the 400-meter distance was 326.9 ± 22.79 s (p=0.22 when compared with Trial 2). Similarly to the assessment of swimming speed, a statistically significant difference occurred when comparing the average time measured at the beginning of the camp and the time measured at the competition (Tukey's test, p=0.03).

Table 2. Mean values and standard deviation of biomechanical variables in 400 m freestyle tests.

	Trial 1	Trial 2	Competition	ANOVA *p* value
Stroke Length (m)	1.83 ± 0.22	1.84 ± 0.22	1.85 ± 0.20	0.95
Stroke Rate (Hz)	0.63 ± 0.07	0.64 ± 0.08	0.65 ± 0.06	0.40
Stroke Index (m^2/s)	2.12 ± 0.36	2.18 ± 0.36	2.29 ± 0.35	0.36
Speed (m/s)	1.15 ± 0.09	1.18 ± 0.08	1.22 ± 0.08	0.03
Time (s)	348.20 ± 28.55	340.60 ± 26.18	326.90 ± 22.79	0.03

The stroke index values showed the strongest correlation with swimming speed evaluated at all test dates (Table 3). A moderate correlation was detected between the stroke length and swimming speed during the competition. The stroke rate turned out to be the least correlated with swimming speed. Only weak correlations between these variables were observed at all test dates.

Table 3. Correlation coefficient for the relationships between average swimming speed of 400 m freestyle and analyzed biomechanical parameters

v 400 m	Stroke Length	Stroke Rate	Stroke Index
Trial 1	0.41	0.23	0.76*
Trial 2	0.33	0.29	0.71*
Competition	0.5*	0.12	0.78*

*p<0.05

Discussion

This study aimed to assess the biomechanical effects of short-term increase of training volume in age-group swimmers. We chose 400 m freestyle performance as the results achieved in this event are a commonly used indicator of aerobic abilities both in young and adult swimmers (da Silva et al., 2020) . Some authors present results of 400 m freestyle biomechanics that are in line with our findings. For example, Zacca et al. (2020) have used the 400 m freestyle test four times in each phase of the 16-week macrocycle performed by 14-year-old swimmers. Analyzing the biomechanical parameters during the macrocycle, the authors noticed substantial changes only in swim speed (v) and distance time (t400). The remaining values of biomechanical variables, i.e. stroke rate, stroke length and stroke index, showed improvement, however without statistically significant differences. Our study covered a three-week period, but our results are similar to those in the study mentioned above - distinct changes were revealed in swimming speed and t400. Similarly, Fereira et al. (2019) examined the changes in biomechanical variables in the 400 m freestyle test performed by 11-year-old children. The analyzed macrocycle was 11 weeks long and the test was performed four times at 3-4 weeks intervals. The authors noted substantial differences in all analyzed biomechanics of 400 m freestyle performance (SL, SR, SI, t400) comparing the results from the successive phases of the macrocycle to the baseline results measured at the beginning of the experiment. In the period between the preparation and specific phases, which is also analyzed in our paper, significant changes were noticed only in stroke index and t400.

The authors of the paper also noted that the stroke index shows the strongest correlation with the swimming speed measured in all four phases of the macrocycle. In our study we found a similar regularity - although the time interval between the first and last study was less than three weeks, the strongest correlation was found between swimming speed and the stroke index. Interesting conclusions can be drawn after reading paper by Latt et al. (2009), where changes in the biomechanical parameters of the 400 m freestyle test were analyzed over two years. The study group consisted of twenty nine 13-year-old boys, who at the beginning of the experiment had a similar anthropometric structure as the participants in our study (average body height = 163.6 cm, average body weight = 51.6 kg, average BMI = 18.9 kg/m^2). Their training experience was three years, just like in our research group. However, the weekly training volume was significantly different - during the studied period, our group spent about 15 hours in water per week, while the swimmers studied by Latt - 8 hours.

The swimmers tested by Latt and colleagues achieved a significant improvement in the 400 m freestyle swimming time after one year. Moreover, substantial changes in the values of biomechanical parameters (v, SL, SR, SI) were observed two years after the first study. The authors did not describe the training characteristics of the group for the next two years of the experiment, so it is impossible to relate the achieved results to the volume or intensity of the training. In our experiment a substantial improvement in 400 m freestyle speed was noted after less than three weeks from the first measurement. We suppose that a significant increase in training volume during the camp resulted in an increase in enzymatic activity to aerobic efforts, which translated into better sports results achieved in competitions. Mezzaroba and Machado (2014) analyzed changes in biomechanical variables over a distance of 400 m freestyle depending on the age of the athletes. In that study, a group of 11 children corresponded to the age of the participants of our experiment. Compared to the athletes we examined, the children from the Mezzaroba's group had lower average swimming speed (v=1.07 m/s), but higher values of stroke length (2.03 m) and stroke index (2.21 m^2/s). The authors also noted a strong correlation between the stroke index and other biomechanical and anthropometric variables. In their opinion, the stroke index is a key element in assessing a young swimmer's sports level.

In this study, it was surprising to see improvements at the end of the camp in both the average values of stroke length and stroke rate. Usually, increase of the stroke rate causes decrease of stroke length and vice versa (Funai, Matsunami, & Taba, 2019). Moreover, under the influence of a substantially increased training volume, an increase in athletes' fatigue could be expected in a short time. Fatigue, on the other hand, influences changes in the stroke rate vs. stroke length ratio (Alberty et al., 2008). We suppose that extending the duration of the camp by a few days could lead to a decrease in SL and SI values, after which the introduction of 10-12 days of regeneration could result in even more pronounced beneficial changes in biomechanical parameters, especially in the stroke index value. A period of eight days of standard (not increased) training volume after the camp resulted in a significant increase in swimming speed during the competition. We believe that in the case of the examined group, the increase in swimming speed was the result of both stroke rate and stroke length, without a clear dominant component.

Conclusions

The highest value of correlation coefficient for the relationship between average swimming speed of 400 m freestyle and stroke index was found for the competition. It was reached by significant increase of stroke length. The non- significant correlation of velocity and stroke length in Trial 2 can be explained by higher focus by the swimmers on stroke rate. Increase of training volume is a strong stimulus for such young athletes which could induced adaptation to the energy cost of swimming at aerobic speeds. It means that one week of conditioning camp with 30% higher volume of training in 6 weeks before the competition could brought on very important impact on the value of stroke index.

The only way to swim faster is increasing the biomechanical parameters. Even one- week training period can positively influence stroke length, stroke rate and stroke index. Increasing the stroke length by 0.54%, the stroke rate by 1.56%, and the stroke index by 2.75% succeeded at 2,54% of higher swimming speed for 400 meters distance. In comparing this results to the data of post-camp training, between Trial 2 and the competitions, we noticed almost the same changes in stroke length (0.54%) and the stroke rate (1.54%).

This study shows that a short-term training camp with an increased training volume can be a means to improve swimming technique and swimming speed. Therefore, it is advisable to organize endurance training camps for age-group swimmers prior to participation in main competition in the macrocycle.

Declaration of Conflicting Interests
Authors declare no conflict of interest.

Acknowledgements
The study was supported by grant 18.610.010-300 by Polish Ministry of Science and Higher Education.
Authors would like to acknowledge Mr. Josh Kelly for proofreading the current paper.

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