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Changes in thrust force in swimmers in the annual training cycle

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Abstract

Study aim: Determination of changes in thrust force and effect size of training load in swimmers using four swimming strokes monitored 4 times a year.

Material and methods: Five elite male swimmers were examined in a training macrocycle of 9 months. The swimmers were examined four times: at baseline (September), immediately after the winter Polish Championships (December), at the end of the transition period (March), and immediately after the summer Polish Championships (late May).

Results: In all participants, significant differences in strength ($p < 0.001$) were observed between measurements I and II ($p < 0.001$) and between measurements I and IV ($p < 0.001$). Athletes specializing in the 200 m were characterized by a smaller decline in thrust force. Athletes specializing in breaststroke had significantly higher ($p < 0.001$) thrust values than the other participants.

Conclusions: It is suggested that the trainers measure the thrust during the preparatory period in order to verify the applied training loads aimed at developing strength, as well as during the starting period to verify the competitor's strength level in correlation with the sports result.

Key words: Thrust force – Annual cycle – Stroke and distance specialization – Swimmers

Introduction

Measuring the value of the force that is developed by an athlete during swimming is of significant interest to sports biomechanists for both theoretical and practical reasons.

Initially, studies of force generated by swimmers concerned those in which the level of this characteristic in the aquatic environment was inferred from dry-land measurements. A test that is also frequently used in swimmers by researchers and coaches is the Wingate test, in which the effort is performed at the maximum frequency of pedaling rate with an individually selected load. A correlation was found between the maximum power obtained in the Wingate test and the maximum force developed in the tethered specific test [24]. It should be noted, however, that the Wingate exercise test is measured on land, which is a different environment than the one in which the swimmer performs most training and competition loads.

However, later studies showed that the physiological response of the body to exercise performed on land differs from that performed in the aquatic environment [33, 34]. Pendergast et al. [25] and Darby and Yaekle [8] proved that exercise of similar intensity can induce a heart rate of more than 10 bpm lower in water than on land. Therefore, the search began for methods that would allow reliable measurements in the aquatic environment and take into account the conditions in which the athlete trains and competes.

It was emphasized that there is a strong correlation between force values in individual muscle groups studied and swimming speed [2, 14, 32]. Specific distributions of muscle force torques were observed in terms of training load and stroke specialization and swimming competition [29].

Knowing the value of the thrust force developed by an athlete is vital to designing training programs. Its values can be measured using thrust force measurement during tethered swimming [22]. Graphic representation of thrust force allows for the determination of not only maximum values but also fatigue thresholds in the athlete [12]. The tethered swimming test can be used to assess the effect of maximal exercise on the energy systems in swimmers while recording the maximum accumulation of lactic acid in the blood [9, 15, 26]. A close correlation was found between the thrust force recorded over the entire course of

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the 60 s exercise and the swimming speed over six repeated 50 m distances. This indicates a high convergence of the two tests in terms of the metabolic area in which both efforts take place [30].

Evaluation of the concentration of lactic acid during the measurement of thrust force for 100 m freestyle swimming in elite athletes revealed that blood lactate levels in swimmers in both tests were high. The coaches' goal was to move the threshold to the right along the X axis that denotes time t[s] [35, 36].

Tethered swimming in freestyle (30 s) was found to highly correlate with 50 m swimming using this swimming stroke [12] and can be used similarly to freestyle to study its individual parameters.

Aspenes et al. [1] conducted maximum muscle strength training over a two-week period and proved that it led to an increase in the value of thrust force and helped maintain the speed over the 400 m freestyle.

Measurement of thrust force is reliable measurement to monitor changes in the athlete's status of functional preparation. Several indicators can be determined from the resulting record of force values, i.e. the maximum force and its maintaining or decrease per unit of time. Swimming is a sport dominated by short – and medium-duration maximum-power efforts, with a predominance of anaerobic metabolism (the duration of ca. 70% of swimming competitions is less than 2 minutes). Measuring thrust force during 60 s efforts makes it possible to assess an athlete's level of strength preparation and test their endurance in a time close to the distance they specialize in (100 m and 200 m) [38].

The main aim of the research is determination of changes in thrust force and effect size of training load in swimmers using four swimming strokes monitored 4 times a year.

Material and methods

Five elite players participated in the measurements. The participants included Olympic athletes and world, European, and Polish champions (Table 1). The results for individual athletes at the distances in which they specialized ranged from 896 to 958 FINA points (The level is based on the qualifying standards set for participation in international events that correspond to ≥ 875 FINA points) [27].

Furthermore, the swimmers were characterized by swimming stroke and distance specialization:

- ✓ butterfly (n = 1 – 50 m and 100 m; n = 1 – 200 m)
- ✓ breaststroke (n = 1 – 50 m I 100 m; n = 1 – 200 m)
- ✓ freestyle (n = 1 – 200 m)

All athletes participated in 4 measurement sessions during the year (Fig. 3.)

When measuring thrust force, the participants swam using four swimming strokes in each measurement session regardless of stroke specialization. With this number of tests, statistical analysis could be performed for such a small group of participants.

All the athletes gave their informed consent to participate in the experiment. Since thrust force measurement is a non-invasive method, approval by the Bioethics Committee was not required.

Measurement of thrust force (60 s) was carried out in the water in a 25 m indoor swimming pool at a water temperature of 27.5°C and humidity of 75%. Each measurement session was preceded by a warm-up in the water (400 m freestyle and 200 m medley). After the warm-up, the participants were given time to rest as needed (about 20 min). Then they performed a 60-second maximum tethered swimming effort, using four swimming strokes (butterfly, backstroke, breaststroke, and freestyle). The test started by floating on the water without pushing off the wall. Each measurement session (I, II, III, IV) lasted 2 days. At this time, the athletes participated in the following measurements: 1st day: butterfly and backstroke, 2nd day: breaststroke and freestyle. After each trial, the athletes had time to rest for ca. 30 min.

Measurements were always taken in the afternoon (between 5 and 7 pm). The research was conducted at the swimming pool of the University of Physical Education in Warsaw.

The MAX-5 measuring station with the Max-5 computer program was used to evaluate thrust force during tethered swimming (Fig. 1). The measurement was made with a strain gauge dynamometer, which sent a signal to a WTP 003 type amplifier connected to a computer (Staniak *Institute of Sport: National Research Institute, Warsaw).*

Table 1. Mean (±SD) and 95% confidence interval for CI mean, and ranges of age, body mass, body height, and training experience in swimmers (n = 5)

	Age [years]	Body mass [kg]	Body height [cm]	Competitive experience [years]
Mean ± SD	22.0 ± 3.1	84.4 ± 7.5	187.8 ± 6.4	12.8 ± 1.6
95% CI mean	18.2 ÷ 25.8	75.0 ÷ 93.8	179.8 ÷ 195.8	10.8 ÷ 14.8
Range (min÷max)	20.0 ÷ 27.0	78.0 ÷ 96.0	182.0 ÷ 198.0	11.0 ÷ 15.0

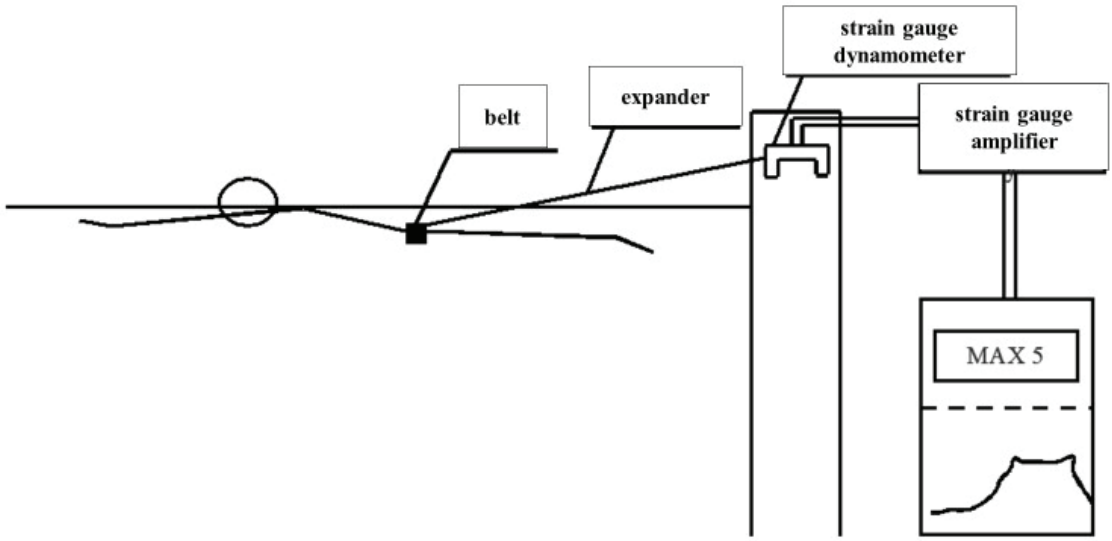


Figure 1. Diagram of the thrust force measuring station

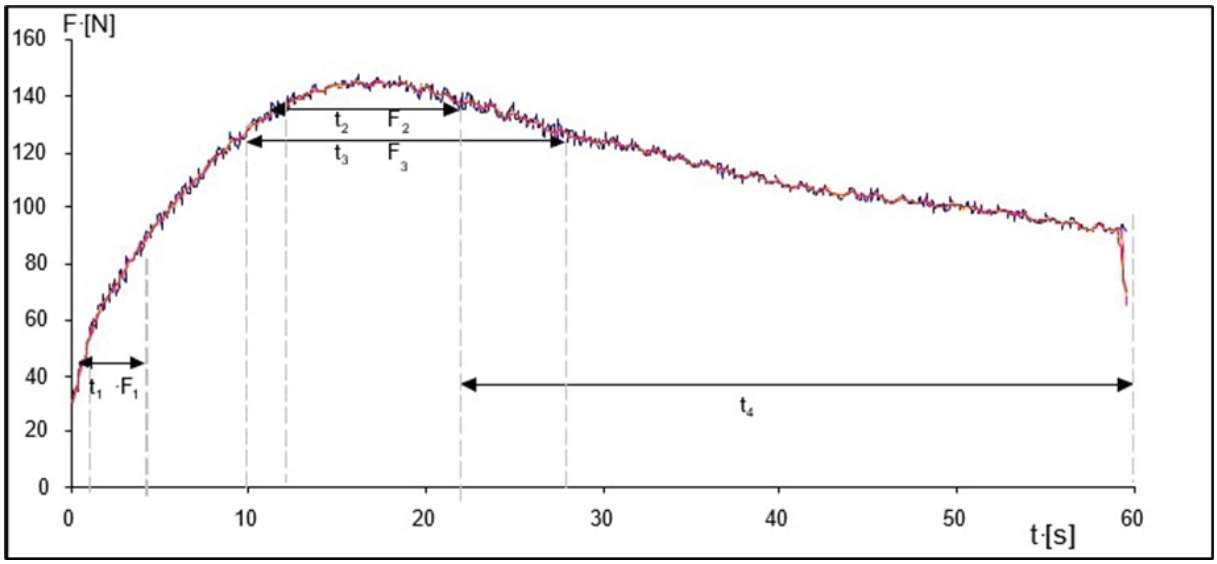


Figure 2. Example of thrust force changes vs. time for a selected athlete

t_1 – force build-up time (20%-50% of max force); t_2 – force maintenance time (over 98% of max force); t_3 – force maintenance time (over 90% of max force); t_4 – force decrease time (max force to the end of the test); F_1 – force, 20 – 50% max thrust force; F_2 – force, > 98% max thrust force; F_3 – force, > 90% max thrust force.

Swimmers were asked to perform an exercise test at an exercise intensity as close to maximum as possible and maintain this level over a test time of 60 s.

The changes in thrust force during the 60 s measurement were analyzed as in the example presented on (Fig. 2).

Ten indicators were calculated to interpret changes in thrust force vs. time. The maximum values of the force, force maintenance capacity and force decline were determined. The decrease in the maximum values of the thrust force Fc vs time was approximated by the simple regression equation F = a – bt (y = a – bx), in which coefficient b describes the value by which the force decreases over time.

The participation of elite swimmers in the experiment posed many difficulties, which were related to the rigorous focus on training and competing in important competitions. Competitors had to participate in four measurement sessions, which were held at intervals of several weeks. This required respondents to be disciplined and highly motivated. Therefore, efforts were made to create conditions for the full involvement of the participants in performing the effort at the highest level. During the experiment, athletes were encouraged to maximize their effort to keep the measured parameter as high as possible until the end of the trial.

The year-long cycle of player preparation lasted 37 weeks and was divided into two mesocycles separated by

a transition period. Each mesocycle included a period of direct pre-competition training which lasted eight weeks (three weeks of accumulation, two weeks of intensification, and three weeks of transformation). The effectiveness of such a design is determined by a gradual increase in the sport-specific exercise and its overall volume from period to period. The first and second mesocycles ended with participation in the main competitions i.e. Polish championships in winter (I) and summer (II), which were the time of peak performance of the athletes in each of these periods. The athletes trained twice a day and six times a week during the macrocycle.

During the entire cycle, 4 measurement sessions (I-September, II-December, III-February, IV-May) were organized according to the coach: the first at the beginning of the macrocycle, the second right after the winter Polish Championships, the third at the end of the transition period, and the fourth right after the summer Polish Championships (Fig. 3).

Total training volume was determined by summing up the volume of training loads related to kilometers the athlete swum with upper limbs, lower limbs, and in full coordination. Analysis of training loads revealed variations of individual parameters as shown in the table below (Table 2).

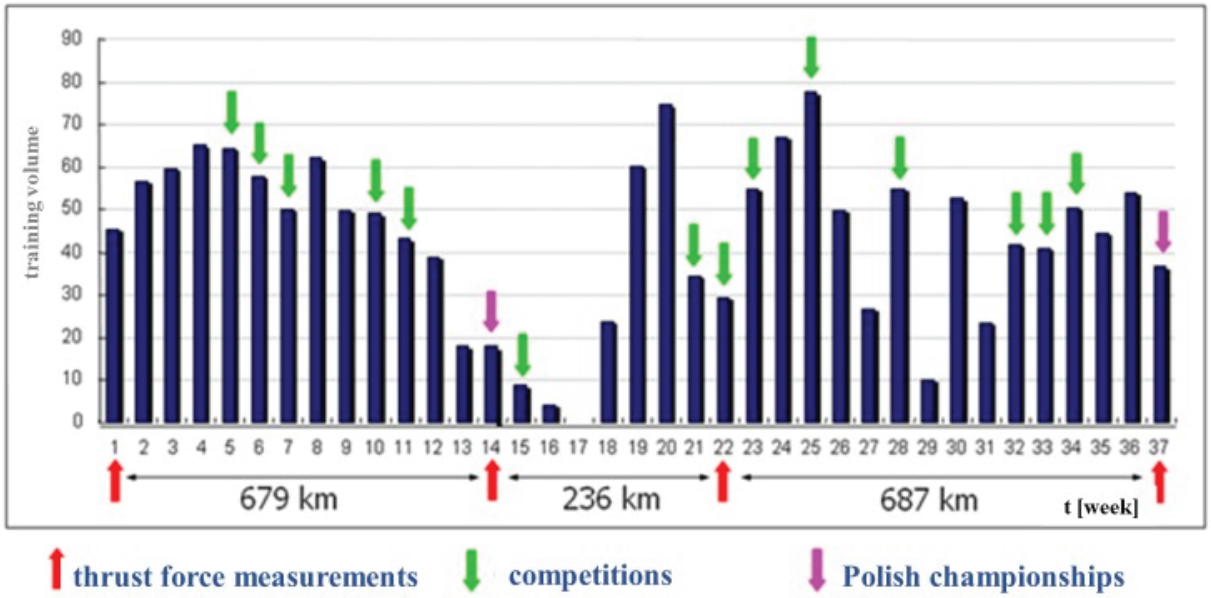


Figure 3. Mean training load volume and measurement schedule

Table 2. The volume of training loads in swimming in the annual training cycle

Athlete stroke specialization		**A** Butterfly (200 m)		**B** Butterfly (50 and 100 m)		**C** Breaststroke (200 m)		D Breaststroke (50 and 100 m)		**E** Freestyle (200 m)	
Number of training sessions		294		341		340		317		337	
Parameters of training load		km	%	km	%	km	%	km	%	km	%
Total swimming volume		1434	100	1701	100	1636	100	1550	100	1690	100
	Butterfly	596	41.6	733	43.1	37	2.3	39	2.5	42	2.5
	Backstroke	19	1.3	19	1.1	20	1.2	19	1.2	20	1.1
	Breaststroke	15	1.0	15	0.9	679	41.5	648	41.9	16	0.9
	Freestyle	443	30.9	510	30.0	490	30.0	457	29.5	1183	70.1
	Medley	259	18.1	292	17.2	286	17.5	268	17.3	298	17.6
	Any	102	7.1	132	7.8	124	7.6	119	7.7	131	7.7
	Upper limbs	184	12.8	217	12.7	219	13.4	215	13.9	224	13.2
	Lower limbs	192	13.4	222	13.1	218	13.4	217	14.0	236	13.9
	Full coordination	1058	73.8	1262	74.2	1199	73.2	1118	72.1	1230	72.9

During the study period, the magnitude of the training load changed according to the macrocycle training plan. Despite the fact that all participants swam a similar number of kilometers per training session per year (an average of 4.8 km to 5 km), the difference in the entire training cycle between the selected athletes was 266 km. Participants did more work in a 25 m swimming pool (about 70%) than in a 50 m pool (about 30%). All of them showed proportion of swimming their favorite stroke, i.e. the one in which the athlete specializes (about 40%) and freestyle (about 70%).

The best measure of performance of an athlete is the results achieved during competitions. Times recorded for an athlete in main and control competitions throughout the training year

All participants showed improved performance at winter and summer national championships. However, all of them performed better in winter than in summer.

Statistical methods

Basic statistical measures were used to characterize the swimmers in terms of the variables studied: arithmetic means (x), standard deviations (± SD), 95% confidence intervals for the mean, and ranges (minimum-maximum). The significance of changes in the mean values of the variables studied induced by training was evaluated using a three-factor analysis of variance (ANOVA) with a mixed design (swimming stroke x distance x training). For significant ANOVA effects, detailed comparisons between pairs of means were made *post hoc* using Tukey's test for different sample sizes. Partial eta-squared (η^2) statistic was used as a measure of effect size. The analysis was made using the statistical package Statistica 13.3 PL. The level of $\alpha = 0.05$ was set to evaluate the significance of differences. A simple regression index was calculated using Excel.

Results

The figures below (Figs. 4–6) show the changes in thrust force over the four measurement sessions for individual swimming strokes.

Based on an ANOVA analysis of variance with mixed design, significant differences were found between swimming strokes in F_1 ($F_{3,29} = 11.19$; $p < 0.001$ $\eta^2 = 0.54$), F_2 ($F_{3,29} = 12.96$; $p < 0.0001$ $\eta^2 = 0.57$), and F_3 ($F_{3,29} = 13.18$; $p < 0.0001$ $\eta^2 = 0.58$).

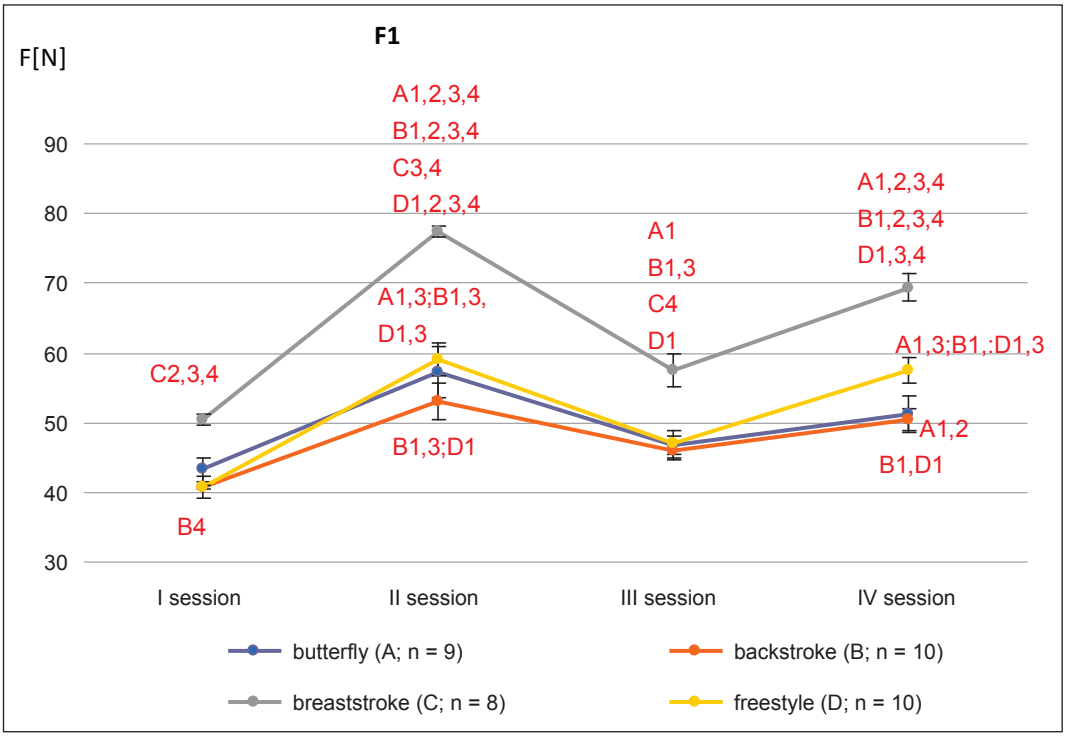


Fig. 4. Mean (±SE) values of thrust force F_1 (20–50% of max thrust force) in the group of swimmers (n = 5) in 4 measurement sessions

A significantly different from butterfly ($p < 0.05$)
B significantly different from backstroke ($p < 0.05$)
C significantly different from breaststroke ($p < 0.05$)
D significantly different from freestyle ($p < 0.05$)

1 – measurement session I
2 – measurement session II
3 – measurement session III
4 – measurement session IV

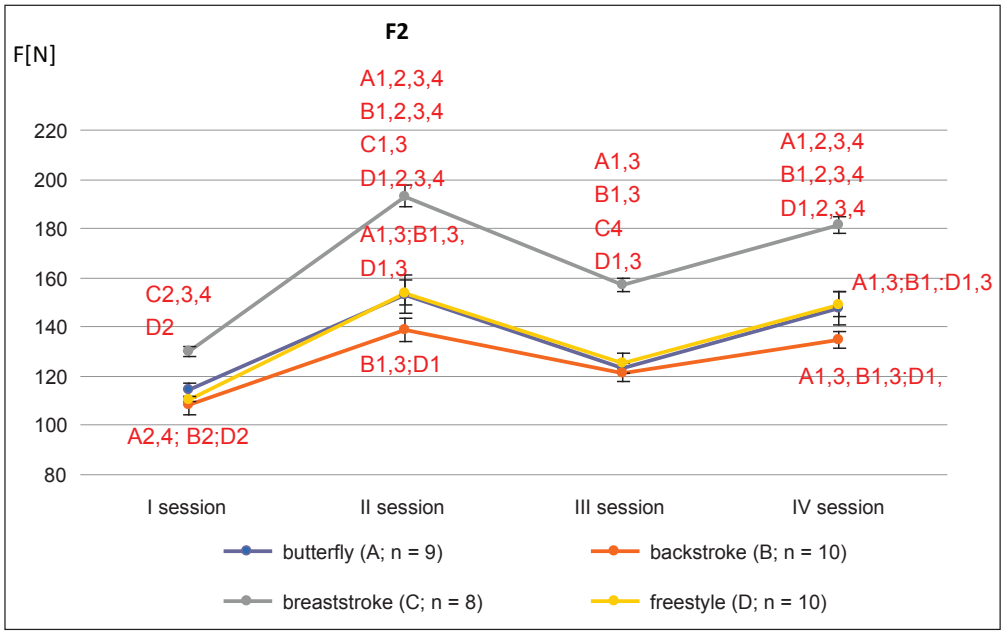


Fig. 5. Mean (±SE) values of thrust force F_2 (> 98% of max thrust force) in the group of swimmers (n = 5) in 4 measurement sessions

A significantly different from butterfly ($p < 0.05$)
B significantly different from backstroke ($p < 0.05$)
C significantly different from breaststroke ($p < 0.05$)
D significantly different from freestyle ($p < 0.05$)

1 – measurement session I
2 – measurement session II
3 – measurement session III
4 – measurement session IV

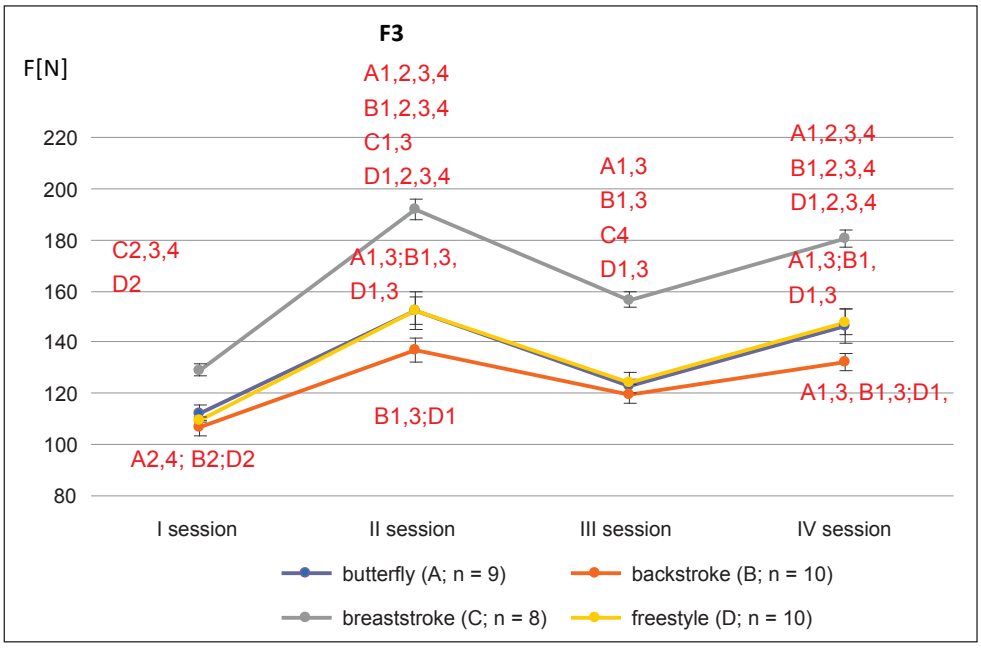


Fig. 6. Mean (±SE) values of thrust force F3 (>90% of max thrust force) in the group of swimmers (n = 5) in 4 measurement sessions

A significantly different from butterfly ($p<0.05$)
B significantly different from backstroke ($p<0.05$)
C significantly different from breaststroke ($p<0.05$)
D significantly different from freestyle ($p<0.05$)

1 – measurement session I
2 – measurement session II
3 – measurement session III
4 – measurement session IV

Tukey's post hoc test revealed that breaststroke swimmers achieved the highest thrust force in measurement session II in parameters F_1 (20–50% of max thrust force), F_2 (>98% of max thrust force), and F_3 (>90% of max thrust force) compared to other strokes ($p < 0.001$).

Based on the analysis of the changes in thrust force over the annual macrocycle, significant differences were found in F_1 ($F_{3,87} = 217.42$; $p < 0.001$, $\eta^2 = 0.88$), F_2 ($F_{3,87} = 247.63$; $p < 0.001$, $\eta^2 = 0.90$), and F_3 ($F_{3,87} = 249.56$; $p < 0.001$, $\eta^2 = 0.90$) in four consecutive measurement sessions. In all swimming strokes, the swimmers obtained significantly higher values of the parameters studied in measurement session II (after the winter championships) compared to measurement sessions I and III. A significant interaction effect for training x stroke ($F_{1;}$ $F_{9,87} = 9.18$; $p < 0.001$; $\eta^2 = 0.49$; $F_{2;}$ $F_{9,87} = 4.41$; $p < 0.001$; $\eta^2 = 0.31$; $F_{3;}$ $F_{9,87} = 4.73$; $p < 0.001$; $\eta^2 = 0.33$) was also found in all parameters determining maximum thrust force (F_1, F_2, F_3). The increments of parameters $F_{1,}$ F_2, and F_3 were significantly greater in measurement session II in swimmers specializing in breaststroke than in the other swimming strokes ($p < 0.001$).

Furthermore, a significant interaction effect was found for the training x distance x stroke factors in F_1 ($F_{9,87} = 2.89$; $p = 0.0049$; $\eta^2 = 0.23$). It was observed that breaststroke swimmers specializing in short distances (50 m and 100 m) obtained significantly higher F_1 values in measurement sessions II and IV compared to those specializing in this stroke at longer distances and other swimmers ($p < 0.01$).

The analysis of the results was also based on t_1 – force build-up time (20%–50% of max force), t_2 – force maintenance time (above 98% of max force); t_3 – force maintenance time (above 90% of max force) and t_4 – force decrease time (max force until the end of the test) (Figs. 7–10). Force build-up time t_1 differed significantly among the swimming strokes studied ($F_{3,29} = 8.16$; $p < 0.001$; $\eta^2 = 0.46$) and varied with training ($F_{3,87} = 0.77$; $p = 0.070$; $\eta^2 = 0.078$). The longest force build-up time of 20%–50% of max force was observed in measurement session II for breaststroke swimming (Fig. 7).

The t_2 parameter differed significantly between swimming strokes ($F_{3,29} = 27.76$; $p < 0.001$; $\eta^2 = 0.74$), while training did not affect its value ($F_{3,87} = 8.42$; $p < 0.001$; $\eta^2 = 0.23$). In measurement sessions I and II, breaststroke swimmers had the longest force build-up time compared to swimmers in other swimming strokes ($p < 0.001$). In measurement sessions III and IV, the t_2 time in breaststroke

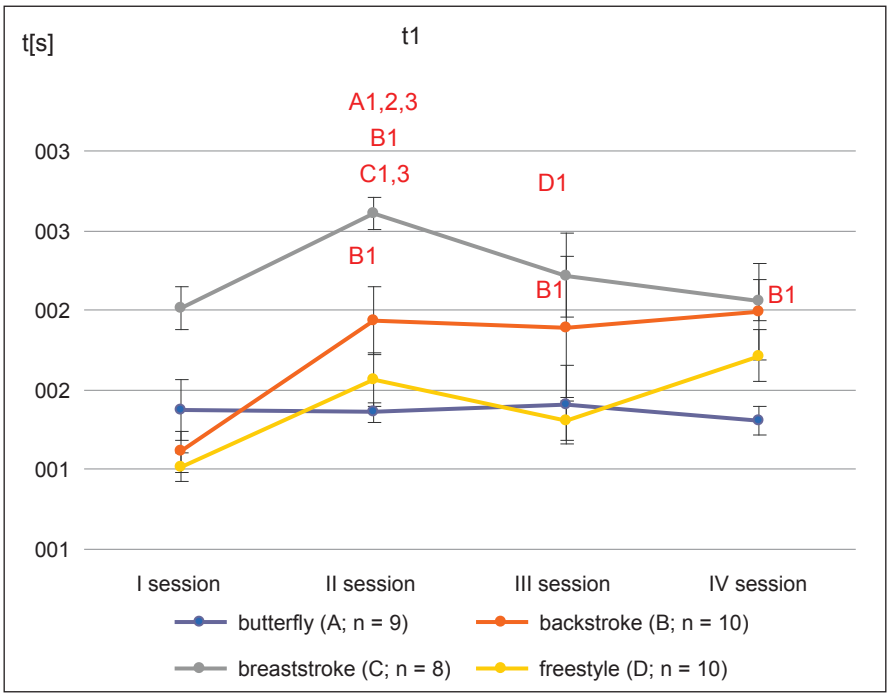


Fig. 7. Mean (±SE) values of t_1 (force build-up time (20%–50% of max force)) in the group of swimmers (n = 5) in 4 measurement sessions

A significantly different from butterfly ($p<0.05$)
B significantly different from backstroke ($p<0.05$)
C significantly different from breaststroke ($p<0.05$)
D significantly different from freestyle ($p<0.05$)

1 – measurement session I
2 – measurement session II
3 – measurement session III
4 – measurement session IV

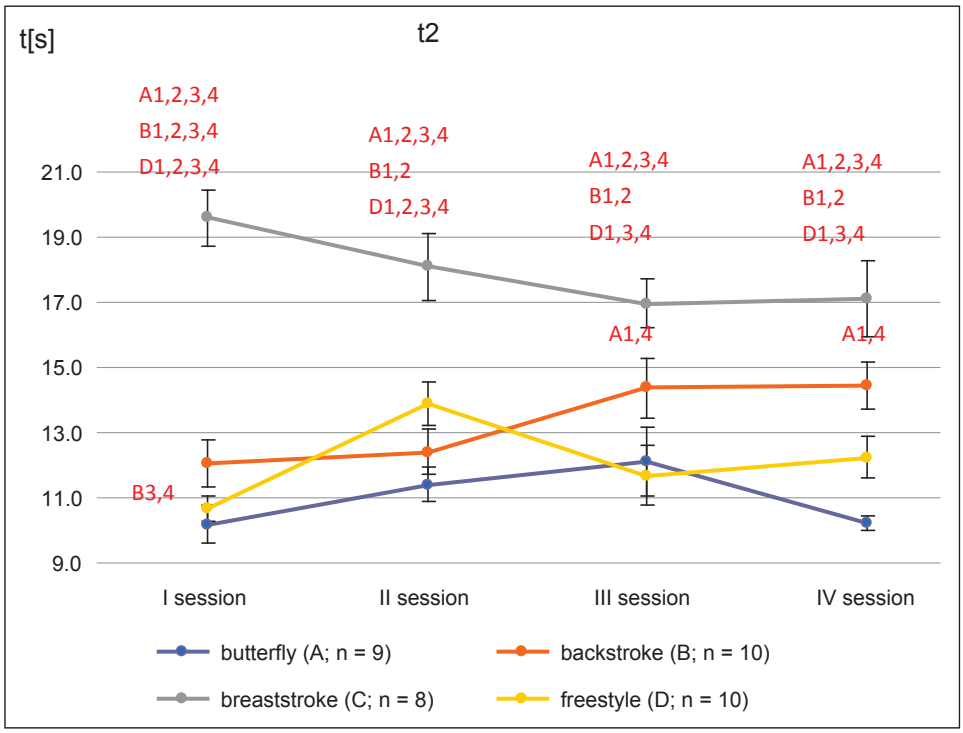


Fig. 8. Mean (±SE) values of t_2 (force maintenance time (over 98% of max force)) in the group of swimmers (n = 5) in 4 measurement sessions

A significantly different from butterfly ($p < 0.05$)
B significantly different from backstroke ($p < 0.05$)
C significantly different from breaststroke ($p < 0.05$)
D significantly different from freestyle ($p < 0.05$)

1 – measurement session I
2 – measurement session II
3 – measurement session III
4 – measurement session IV

differed significantly from butterfly and freestyle, while there were no significant differences between t_2 values for breaststroke and backstroke (Fig. 8). In this parameter, a significant interaction effect was observed for the training x stroke factors ($F_{9,87} = 3.67$; $p < 0.001$; $\eta^2 = 0.27$) (Fig. 8) and for the training x distance factors $F_{3,87} = 3.14$; $p = 0.03$; $\eta^2 = 0.10$). Larger increments of force build-up time in measurement session III were recorded in long-distance than in short-distance swimmers.

In t_2 and t_3, significant differences were found between long – and short-distance swimmers (t_2; $F_{1,29} = 4.05$; $p = 0.045$; $\eta^2 = 0.15$; t_3; $F_{1,29} = 5.62$; $p = 0.025$; $\eta^2 = 0.16$) in favor of the former. Significant differences were observed for swimming strokes, with swimmers specializing in breaststroke achieving significantly longer time to maintain max thrust force than those of other swimming strokes ($F_{3,29} = 25.24$; $p < 0.001$; $\eta^2 = 0.72$). Furthermore, a significant interaction effect was found for the training x stroke factors ($F_{9,87} = 4.88$; $p < 0.001$; $\eta^2 = 0.34$).

In parameter t_4 (force decrease time (max force to the end of the test)), significantly lower values were recorded in swimmers of different stroke specializations ($F_{3,29} = 4.63$; $p = 0.009$ $\eta^2 = 0.32$), where in measurement session I the force decrease time was significantly shorter in butterfly compared to breaststroke and backstroke. A significant interaction was also found for factors distance x stroke ($F_{3,29} = 5.37$; $p = 0.005$; $\eta^2 = 0.36$), training x stroke ($F_{9,87} = 3.11$; $p = 0.003$; $\eta^2 = 0.24$) and training x distance x stroke ($F_{9,87} = 2.58$; $p = 0.01$; $\eta^2 = 0.21$). Force decrease time t_4 was longer for long-distance freestyle and breaststroke swimmers while it was shorter for backstroke and freestyle athletes; the opposite was true for short-distance swimmers.

In athletes specializing in longer distances, the decrease in maximum values vs. time was smaller compared to swimmers specializing in shorter distances (50 and 100 m). The coefficient b determining the decrease in maximum force vs. time in long-distance swimmers during the competitive periods (measurement sessions II and IV) was b = –5, while in short-distance runners in the same measurement sessions, it was b = –10.

The decrease in the value of strength is associated with training loads (Fig. 11).

Swimmers specializing in the 50 m distance spent a greater proportion of their time on sprint training throughout the year (80% in the macrocycle), while those specializing in the 200 m performed 20% more training loads involving endurance training than sprinters (50 m)

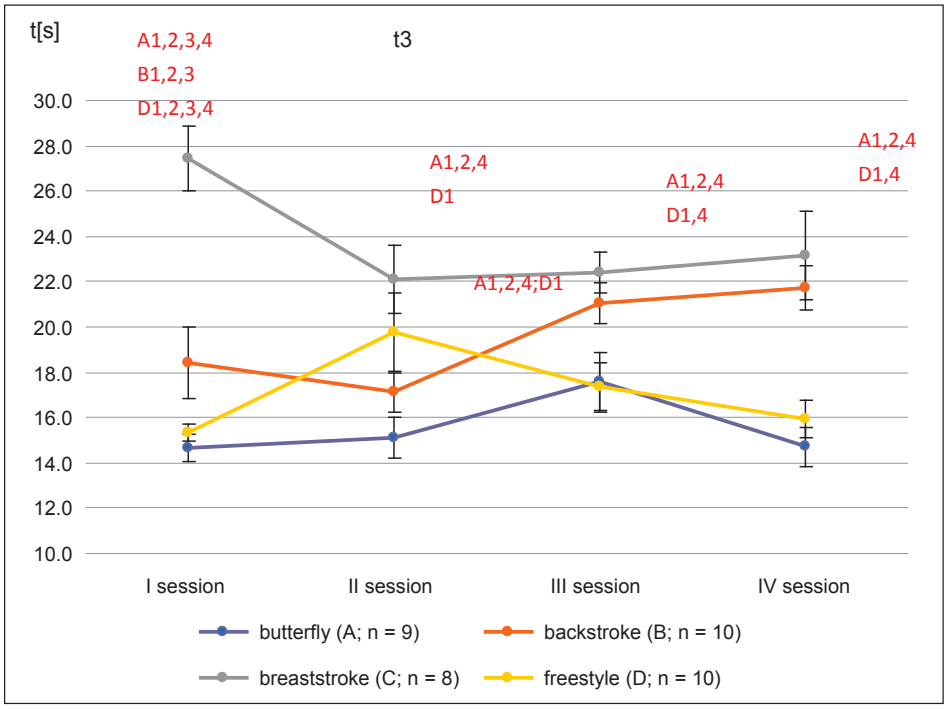


Fig. 9. Mean (±SE) values of t_3 (force maintenance time (over 90% of max force)) in the group of swimmers (n = 5) in 4 measurement sessions

A significantly different from butterfly ($p < 0.05$)
B significantly different from backstroke ($p < 0.05$)
C significantly different from breaststroke ($p < 0.05$)
D significantly different from freestyle ($p < 0.05$)

1 – measurement session I
2 – measurement session II
3 – measurement session III
4 – measurement session IV

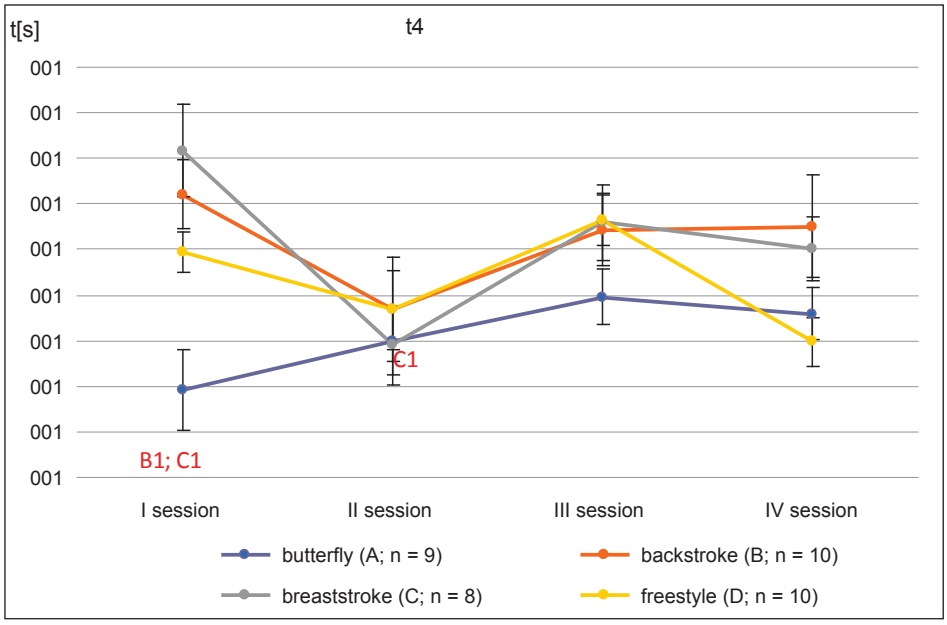


Fig. 10. Mean (±SE) values of t_4 (force decrease time (max force to the end of the test)) in the group of swimmers (n = 5) in 4 measurement sessions

A significantly different from butterfly ($p < 0.05$)
B significantly different from backstroke ($p < 0.05$)
C significantly different from breaststroke ($p < 0.05$)
D significantly different from freestyle ($p < 0.05$)

1 – measurement session I
2 – measurement session II
3 – measurement session III
4 – measurement session IV

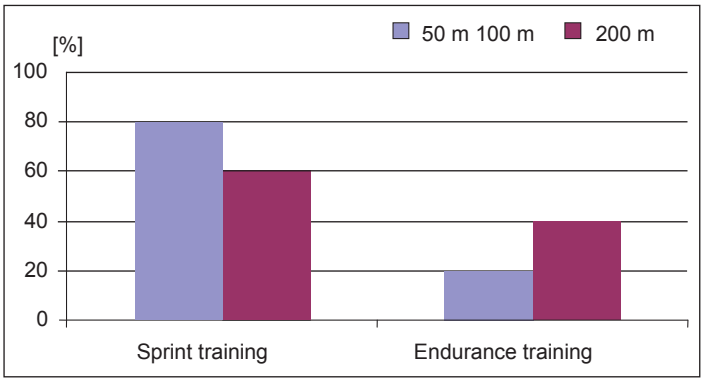


Fig. 11. Percentage of endurance and sprint training volume in the annual training macrocycle in athletes specializing in the 50 m, 100 m, and 200 m

(Fig. 11). At the beginning of the preparatory period, all the participants swam longer distances (to improve endurance). The nature and tasks of the individual training loads changed as the main competition approached, and were consistent with stroke and distance specialization.

Discussion

Evaluation of current strength and endurance is crucial for training control [16, 17, 21]. Data on an athlete's submaximal and maximal exercise capacity are fundamental to the training cycle as they allow the coach to manipulate the training parameters to efficiently changed exercise intensity [30]. In the present study, the results indicated significant changes in the level of strength in athletes during the annual training cycle. Therefore, it can be expected that the changes in strength were influenced by training loads specific to particular periods of the training cycle, closely related to the athlete's specialization in a particular swimming stroke and distance. Similar changes have been reported by other researchers [3, 20, 31], who found that training loads had an effect on strength, fitness, and swimming speed in swimming over their training cycles.

Analysis of training volume in terms of total kilometers swum reveals that during the preparatory period, swimmers specializing in a particular swimming stroke performed the majority of training tasks (ca. 40%) using this stroke. Morales [23] argued that specialization in a particular swimming stroke accounts for ca. 50% of the total training work, including all the intensity ranges used with this stroke.

Analysis of the training load in the athletes studied shows that the tasks took a variety of forms and structures and the increments of training load in the analyzed annual macrocycle also varied, especially in those stages of the competitive season where the main training goals were related to the competitions in a specific distance. Similar examples of planning training loads throughout the year were presented by Hannula and Thornton [19], with the volume and intensity of training loads closely linked to the competition schedule and preparation for major competitions.

Detailed analysis showed that all the participants achieved the highest maximum thrust force in the same periods (winter and summer Polish championships). It can also be concluded that the trend of changes in muscle strength levels throughout the training cycle was similar in all swimmers.

During tethered swimming measurements, it was observed that athletes specializing in breaststroke were able to maintain maximum thrust force for the longest time and that the force curves were characterized by the smallest drop before 60 seconds of measurement compared to other swimming strokes (butterfly, backstroke, and freestyle). Similarly, in a study by Chollet et al. [6], the authors observed a correlation between upper and lower limb work and the streamline phase in breaststroke. Reducing the glide time and increasing the frequency of upper and lower limbs had a significant effect on thrust force.

The analysis of thrust force values indicated differences in the ability to maintain maximum force by the swimmers specializing in different distances (50 m and 100 m vs. 200 m) [36], during a maximum-intensity exercise performed for 60 seconds. The time during which an athlete can maintain a maximum force in an exercise test is valuable information regarding the fatigue processes taking place in the skeletal muscles of the athlete [18]. In the training program developed for the study group, differences can be observed in the percentage of endurance and sprint training. The largest percentage differences in the proportion of training loads in athletes specializing in the 50 m and 200 m and those specializing in the 200 m were observed during the competitive season. Swimmers specializing in the 50 m and 100 m spent a greater proportion

of their time on sprint training throughout the year (80% in the macrocycle), while those specializing in the 200 m performed 20% more training loads involving endurance training than sprinters (50 m and 100 m). Therefore, athletes specializing in sprint distances (50 m and 100 m) achieved higher maximum thrust force in a shorter time, at around 10s of measurement in the second and fourth measurement sessions. In contrast, athletes specializing in the 200 m, during the same period, reached maximum force values much later (at around 20s of measurement) but maintained thrust force in the 90%–90% range for much longer. Furthermore, athletes specializing in the 200 m achieved lower thrust force values than sprinters (50 m and 100 m). Other researchers studied neuromuscular fatigue and observed a failure to maintain the required or expected force, accompanied by changes in muscle activity [4, 5] and also found the changes that occur in muscle activity over the 200 m breaststroke [7], which significantly differentiates the exercise over this distance from 50 m and 100 m [27, 32]. Differences in the kinematics of breaststroke movements for 100 m and 200 m swimming were also demonstrated, confirming the differences that were observed during the measurements of thrust force in swimmers specializing in short distances (50 m and 100 m) and 200 m [37].

The effective development of sports performance and its stability depend on the amount and type of training work. The best measure of the performance of an athlete is the results achieved during competitions. Differences in training status increased with training loads and entailed favorable changes in swimming speed. Moreover, the results obtained in the study lead to the conclusion that the training, especially in the winter season, was comprehensive in nature. The best results in all athletes were recorded in the winter season (December). The results indicate that the participants were well prepared for the winter Polish championships, where four of them took first place and improved their personal records in the 25-meter swimming pool. On the other hand, in the summer championships, only athlete B ranked highest in the country and achieved a better result than his personal record in the 50-meter swim. The others placed in the top four and with worse results than their personal records on the long swimming pool (50 m).

Further improvements in personal records are therefore contingent on the continuous development and updating of the coaching competencies not only with new experiences but also based on information from scientific knowledge.

Lack of knowledge of the strength capabilities of athletes specializing in different swimming strokes and using too high or too low training loads consequently limits their achievement of the correct level of development of this physical trait and their ability to use their strength potential in swimming.

Conclusions

The results of the present study in this paper allow a positive evaluation of the changes in strength induced by training loads used in swimmers over an annual cycle.

- ✓ The training loads used in the winter season resulted in greater changes in thrust force than the training loads in the summer season, with all participants showing improved sports performance in the winter Polish Championships. Therefore, training loads in the summer season should be modified to meet the needs of the athletes.
- ✓ The volume and nature of the training load differed among the participants due to distance specialization, and, therefore, different patterns of thrust force can be observed in short – and long-distance swimmers. A smaller decrease in maximum strength values was noted in swimmers specializing in the 200 m compared to those competing in short distances. This is characteristic of distance specialization.
- ✓ The nature of the movement of the upper and lower limbs in breaststroke differs from other swimming strokes. Therefore, regardless of distance specialization, swimmers specializing in this stroke had significantly higher parameters of thrust force than other participants. This was due to the shortening of the streamline phase and increased frequency in swimmers specializing in breaststroke.
- ✓ The measurement of the thrust force provides the coach with information about the athlete's strength predispositions in a given period of the training cycle and whether the applied training loads aimed at shaping the strength of swimmers translate into sports results. It is suggested that coaches measure the thrust during the preparatory period in order to verify the applied training loads aimed at developing strength, as well as during the starting period to verify the competitor's strength level in correlation with the sports result.

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References

1. Aspenes S., Kjendlie P.L., Hoff J. (2009) Helgerud J. Combined strength and endurance training in competitive swimmers. *J. Sports Sci. Med.*, 8(3): 357-365.
2. Aujouannet Y.A., Bonifazi M., Hintzy F., Vuillerme N., Rouard A.H. (2006) Effects of a high-intensity swim test on kinematic parameters in high-level athletes. *Appl. Physiol. Nutr. Metab.*, 31(2): 150-158. DOI: 10.1139/h05-012.
3. Avalos M., Hellard P., Chatard J.C. (2003) Modeling the training-performance relationship using a mixed model in

elite swimmers. *Med. Sci. Sports Exerc.*, 35(5): 838-846. DOI: 10.1249/01.MSS.0000065004.05033.42.
4. Caty V., Hintzy F., Aujouannet Y., Molinari F., Knaflitz M. (2006) Time-frequency parameters of wrist muscles EMG after an exhaustive freestyle test. *Revista Portuguesa de Ciencias do Desport,* 6: 28-30.
5. Caty V., Aujouannet Y., Hintzy F., Bonifazi M., Clarys J.P., Rouard A.H. (2007) Wrist stabilisation and forearm muscle coactivation during freestyle swimming. *J. Electromyogr. Kinesiol.*, 17(3): 285-291. DOI: 10.1016/j.jelekin.2006.02.005.
6. Chollet D., Seifert L., Leblanc H., Boulesteix L., Carter M. (2004) Evaluation of arm-leg coordination in flat breaststroke. *Int. J. Sports Med.*, 25(7): 486-495. DOI: 10.1055/s-2004-820943.
7. Conceição A., Puel F., Louro H., Morgado S., Seifert L. (2018) Effect of glide on neuromuscular adaptation in breaststroke swimming a case study of an elite swimmer. *Sci. Int. (Lahore)*, 30(2): 233-237, ISSN 1013-5316.
8. Darby L.A., Yaekle B.C. (2000) Physiological responses during two types of exercise performed on land and in the water. *J. Sports Med. Phys. Fitness*, 40: 303-311.
9. Dekerle J., Baron B., Dupont L., Vanvelcenaher J., Pelayo P. (2003) Maximal lactate steady state, respiratory compensation threshold and critical power. *Eur. J. Appl. Physiol.*, 89(3-4): 281-288. DOI: 10.1007/s00421-002-0786-y.
10. Dekerle J., Nesi X., Lefevre T., Depretz S., Sidney M., Marchand F.H., Pelayo P. (2005) Stroking parameters in front crawl swimming and maximal lactate steady state velocity. *Int. J. Sports Med.*, 26(1): 53-58. DOI: 10.1055/s-2004-817854.
11. Dekerle J., Brickley G., Alberty M., Pelayo P. (2009) Characterising the slope of the distance-time relationship in swimming. *J. Sci. Med. Sport*, 13(3): 365-370. DOI: 10.1016/j.jsams.2009.05.007.
12. Dopsaj M., Matković I., Zdravković I. (2000) The relationship between 50 m-freestyle results and characteristics of tethered forces in male sprint swimmers: a new approach to tethered swimming test. Facta Universitatis – Series: *Physical Education and Sport*, 1(7): 15-22.
13. Dopsaj M., Matković I., Thanopoulos V., Okičić T. (2003) Reliability and validity of basic kinematics and mechanical characteristics of pulling force in swimmers measured by method of tethered swimming with maximum intensity of 60 seconds. Facta Universitatis – Series: *Physical Education and Sport*, 1(10): 11-22.
14. Figueiredo P., Sousa A., Goncalves P., Pereira S.M., Soares S., Vilas-Boas J.P., Fernandes R.J. (2010) Biophysical Analysis of the 200 m Front Crawl Swimming: a Case Study. In: Biomechanics and Medicine in Swimming XI, P.L.
15. Greenwood J.D., Moses G.E., Bernardino F.M., Gaesser G.A., Weltman A. (2008) Intensity of exercise recovery, blood lactate disappearance, and subsequent swimming performance. *J. Sports Sci*., 26(1): 29-34. DOI: 10.1080/02640410701287263.
16. Girold S., Calmels P., Maurin D., Milhau N., Chatard J.C. (2006) Assisted and resisted sprint training in swimming. *J. Strength Condit. Res.*, 20(3): 547-554. DOI: 10.1519/R-16754.1.
17. Girold S., Maurin D., Dugué B., Chatard J.C., Millet G. (2007) Effects of dry-land vs. Resisted – and assisted-sprint exercises on swimming sprint performances. *J. Strength Cond. Res.*, 21(2): 599-605. DOI: 10.1519/R-19695.1.
18. Górski J. (2006) Fizjologiczne podstawy wysiłku fizycznego Wyd. Lekarskie PZWL Warszawa.
19. Hannula D., Thornton N. (2012) The Swim Coaching Bible, Vol. II. Human Kinetics.
20. Hellard P., Avalos M., Lacoste L., Barale F., Chatard J.C., Millet G.P. (2006) Assessing the limitations of the Banister model in monitoring training. *J. Sports Sci.*, 24(5): 509-520. DOI: 10.1080/02640410500244697.
21. Hoff J., Gran A., Helgerud J. (2002) Maximal strength training improves aerobic endurance performance. *Scand. J. Med. Sci. Sports*, 12(5): 288-295. DOI: 10.1034/j.1600-0838.2002.01140.x.
22. Huang Z., Kurobe K., Nishiwaki M., Ozawa G., Tanaka T., Taguchi N., Ogita F. (2010) Relationship between Propelling Efficiency and Swimming Performance in Elite Swimmers. XI International Symposium on Biomechanics and Medicine in Swimming Oslo, Norway, pp. 201-203.
23. Morales P. (2001) Butterflay training. (w) The swim coaching bible. Human Kinetics Publishers Champaign. Illinois.
24. Ogonowska A, Hübner-Woźniak E, Kosmol A, Gromisz W. (2009) Anaerobic capacity of upper extremity muscles of male and female swimmers. *Biomed. Hum. Kinet.,* 1: 79-82.
25. Pendergast D., Zamparo P., di Prampero P.E. (2003) Energy balance of human locomotion in water. *Eur. J. Appl. Physiol.*, 90: 377-386. DOI: 10.1007/s00421-003-0919-y
26. Pessôa Filho D.M., Denadai B.S. (2010) Extending the Critical Force Model to Approach Critical Power in Tethered Swimming, and its Relationship to the Indices at Maximal Lactate Steady-State. XI International Symposium on Biomechanics and Medicine in Swimming Oslo, Norway, pp.151-153.
27. Puce L., Pallecchi I., Marinelli L., Mori L., Bove M., Diotti D., et al. (2021). Surface electromyography spectral parameters for the study of muscle fatigue in swimming. *Front. Sports Act. Living* 3: 644765. DOI: 10.3389/fspor.2021.644765.
28. Ruiz-Navarro, J.J., López-Belmonte, Ó., Gay, A., Cuenca-Fernandez, F. and Arellano, R., (2022) A new model of performance classification to standardize the research

results in swimming. *European Journal of Sport Science*, pp. 1-11. DOI: 10.1080/17461391.2022.2046174.
29. Stachowicz M., Iwańska D., Gajewski J., Słomiński P., Urbanik Cz. (2006) Muscle torques in swimmers throughout a trainig macrocycle. *Phys. Educ. Sport*, 50: 39-42.
30. Stanula A., Gromisz W., Szmatlan-Gabryś U., Gabryś T. (2005) The measurement of strength of draught in water as method of diagnosis of anaerobic efficiency disabled swimmers. AWF Katowice, vol. LX, suppl. XVI, 506, pp. 239-243.
31. Stewart A.M., Hopkins W.G. (2000) Seasonal training and performance of competitive swimmers. *J. Sports Sci.*, 18(11): 873-884. DOI: 10.1080/026404100750017805.
32. Stirn I., Jarm T., Kapus V., Strojnik V. (2011). Evaluation of muscle fatigue during 100-m front crawl. *Eur. J. Appl. Physiol*. 111: 101-113. DOI: 10.1007/s00421-010-1624-2, PMID.
33. Tanaka H. (2009) Swimming exercise: impact of aquatic exercise on cardiovascular health. *Sports Med.*, 39(5): 377-387. DOI: 10.2165/00007256-200939050-00004.
34. Tanaka H., Sommerlad S.M., Renzi C.P., Barnes J.N., Nualnim N. (2010) Post-exercise Hypotension and Blood Lipoprotein Changes following Swimming Exercise. XI International Symposium on Biomechanics and Medicine in Swimming Oslo, Norway, pp. 381-383.
35. Thanopoulos V., Platanou, Rozi G. (2009) Maximum accumulation of lactic acid in freestyle and tethered swimming. 11th International Conference of Sport Kinetics. Abstract book. p. 201.
36. Thanopoulos, V., Rozi, G., Platanou, T.Lactate Comparison Between 100 m Freestyle and Tethered Swimming of Equal Duration. (2010) XI International Symposium on Biomechanics and Medicine in Swimming Oslo, Norway 2010, pp. 230-233.
37. Thompson K.G., Haljand R., MacLaren D.P. (2000) An analysis of selected kinematic variables in national and elite and female 100 m and 200 m breaststroke swimmers. *J. Sports Sci.*, 18(6): 421-431. DOI: 10.1080/02640410050074359.

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