European Journal of Sport Science

ISSN: 1746-1391 (Print) 1536-7290 (Online) Journal homepage: http://www.tandfonline.com/loi/tejs20

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To cite this article: Mariusz Naczk, Artur Lopacinski, Wioletta Brzenczek-Owczarzak, Jarosław Arlet, Alicja Naczk & Zdzisław Adach (2016): Influence of short-term inertial training on swimming performance in young swimmers, European Journal of Sport Science, DOI: 10.1080/17461391.2016.1241304

To link to this article: http://dx.doi.org/10.1080/17461391.2016.1241304

Published online: 19 Oct 2016.

European Journal of Sport Science, 2016
http://dx.doi.org/10.1080/17461391.2016.1241304

ORIGINAL ARTICLE

Influence of short-term inertial training on swimming performance in young swimmers

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Abstract
The aim of this study was to evaluate the influence of dry-land inertial training (IT) on muscle force, muscle power, and swimming performance. Fourteen young, national-level, competitive swimmers were randomly divided into IT and control (C) groups. The experiment lasted four weeks, during which time both groups underwent their regular swimming training. In addition, the IT group underwent IT using the Inertial Training Measurement System (ITMS) three times per week. The muscle groups involved during the upsweep phase of the arm stroke in front crawl and butterfly stroke were trained. Before and after training, muscle force and power were measured under IT conditions. Simultaneously with the biomechanical measurements on the ITMS, the electrical activity of the triceps brachii was registered. After four weeks of training, a 12.8% increase in the muscle force and 14.2% increase in the muscle power ($p < .05$) were noted in the IT group. Moreover, electromyography amplitude of triceps brachii recorded during strength measurements increased by 22.7% in the IT group. Moreover, swimming velocity in the 100 m butterfly and 50 m freestyle improved significantly following the four weeks of dry-land IT (−1.86% and −0.76%, respectively). Changes in the C group were trivial. Moreover, values of force and power registered during the ITMS test correlated negatively with the 100 m butterfly and 50 m freestyle swimming times (r value ranged from −.80 to −.91). These results suggest that IT can be useful in swimming practice.

Keywords: *Strength, power transfer, swimming velocity*

Introduction

Many anthropometrical, physiological, and biomechanical parameters influence one's swimming performance (Jürimäe et al., 2007). However, muscle strength and power strongly impact a sprint swimmer's performance during training and competition (Costill, King, Holdren, & Hargreaves, 1983; Garrido, Marinho, Barbosa, et al., 2010; Girold, Maurin, Dugué, Chatard, & Millet, 2007; Newton, Jones, Kraemer, & Wardle, 2002). The need for adequate muscle strength is confirmed by the significant association between upper-body muscular strength and swim velocity over short swimming distances (Hawley & Williams, 1991). Moreover, some studies confirmed that dry-land strength training improved swimming performance (Girold et al., 2007; Strass, 1988), although a gain on land does not always transfer to swimming performance (Tanaka, Costill, Thomas, Fink, & Widrick, 1993). Tanaka et al. (1993) stated the lack of positive transfer between dry-land strength gains and swimming propulsive force may be due to the specificity of training. In the last decade, influence of dry-land strength training on swimming performance in young swimmers has been studied more often than before. Garrido, Marinho, Reis, et al. (2010) stated that they cannot clearly state that strength training allowed an enhancement in swimming performance, although a tendency to improve sprint performance due to strength training was noticed. Potdevin, Alberty, Chevutschi, Pelayo, and Sidney (2011) strongly suggested to incorporate plyometric training in pubescent swimmers training. Researches still try to modify dry-land strength training for young swimmers; the study of Pešić et al. (2015) showed that

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additional strength training programme performed by 10–12-year-old swimmers leads to significant (compared to the control group) improvements in breaststroke start time for the 10 m swim, swim time for the 10 m swim, and turn length. However, these authors also stated that their experimental programme would require modification in the further training process with a view to achieving more considerable training effects.

One strength training method which has not been tested in swimming practice is inertial training (IT), which differs from traditional dry-land resistance training. In traditional training, due to earth's gravity, weight of dumbbells or barbells loads muscles during training. In the IT, the role of the gravity acceleration is irrelevant. During the concentric phase of exercise, muscles accelerate the load. When the accelerated mass exceeds the turning point, there begins a strong eccentric contraction of the muscles. For example, during knee extension exercise, the participant tries to straighten his knee throughout the exercise, and knee joint flexion is only forced by the flywheel mass of inertia (Naczk, Naczk, Brzenczek-Owczarzak, Arlet, & Adach, 2015).

In the IT method, a specialized device that utilizes inertial resistance is needed. Although the principles of this training are not well known, some studies involving untrained participants showed that IT can lead to significant improvement of muscle strength and power in a short time (Brzenczek-Owczarzak et al., 2013; Naczk, Naczk, Brzenczek-Owczarzak, Arlet, & Adach, 2016; Seynnes, de Boer, & Narici, 2007). Moreover, Onambele et al. (2008) proved that IT of the main locomotor muscles (knee extensors) results in greater improvements in muscle peak power and balance than weight training. It is possible that IT can be more effective than traditional strength training also in sport practice. Only one study concerning the influence of inertial exercise (not training) on swimming performance was published (Cuenca-Fernández, López-Contreras, & Arellano, 2015), and the authors stated that four repetitions on the inertial device YoYo squat performed during warm-up lead to a greater improvement in the performance of the swimmer's start than three lunge repetitions at 85%, one repetition maximum. Cuenca-Fernández et al. (2015) concluded that inertial exercises evoke positive influence on post-activation potentiation and can be used as a part of warm-up before swimming competition, especially in short events. However, the efficacy of IT in sport practices has rarely been studied. To the best of our knowledge, only two studies were published (Davison et al., 2010; McLoda, Murphy, & Davison, 2003) and both concerned the influence of IT on ball throwing efficacy in baseball. McLoda et al. (2003) stated that four weeks of IT did not improve throwing velocity of the ball in college baseball and softball players. However, Davison et al. (2010) found that baseball pitch velocity significantly increased after 20 weeks of IT in adolescent baseball players. Moreover, Caruso et al. (2006) stated that IT should improve sports performance, for example, in volleyball, and basketball; however, the authors did not verify this hypothesis. Therefore, we can state that IT is novel in sport practice. One of the devices used in IT is the Inertial Training Measurement System (ITMS). The ITMS allows specific movements to be performed that are typical of various sports disciplines, including swimming. It is noteworthy that ITMS system allows online control and registration of training parameters (peak force, mean force, power, work, time, and number of cycles). Therefore, ITMS theoretically could be used for strength and conditioning programme for young swimmers. Moreover, thanks to technological solutions used in ITMS monitoring of strength progress is also possible. However, so far, IT never has been tested in swimming practice.

In view of the above, the aim of this study was to evaluate the influence of dry-land IT on the muscle force, muscle power, and swimming performance. This is the first evaluation of effectiveness of IT in swimming practice. Based on the high efficiency of IT in the above-mentioned studies, we hypothesized that there would be a positive influence of dry-land IT on the muscle strength, power and swimming performances.

Methods

Participants

A group of 14 national-level competitive swimmers (10 men, 4 women; swimmers were ranked between 4th and 32nd places on the national championship; mean ± SD, age: 15.8 ± 0.4 years, height: 1.79 ± 0.07 m, weight: 69 ± 8 kg) took part in this study – convenience sample. The participants were randomly divided into two groups: IT ($n = 7$, five men and two women) and control (C; $n = 7$, five men and two women). Swimmers met the following inclusion criteria: they were sprinters and they had a minimum of six years of practice. The exclusion criteria were: injury in the last three months or any other cause of exclusion from training for more than one week in the last three months, lack of parental informed consent for children's research participation. None of the swimmers who met the above-mentioned criteria resigned from participation in the experiment during the four weeks. All participants and their parents were informed about the procedures, risks, and benefits. Swimmers and their parents provided signed informed consent. Swimmers participated in the study on a voluntary basis. All procedures were approved by the local ethical committee, with approval based on the Declaration of Helsinki.

Workouts

All swimmers participated in their routine swimming training. They were trained for an average of 1 h and 45 min 11 times per week in a 50 m swimming pool. In addition, the IT group underwent training with the ITMS, which has been described by Naczk et al. (2016). The participant position and movement technique during IT were the same as during measurements (see below). IT was performed three times per week (Monday, Wednesday, and Friday) for four weeks at the end of preparatory period – the first competition was held a week after the experiment. Other studies indicate that 4–5 weeks of IT is sufficient to increase the muscle strength and power in young and middle-aged men (Naczk, Brzenczek-Owczarzak, Arlet, Naczk, & Adach, 2014; Naczk et al., 2016; Norrbrand, Fluckey, Pozzo, & Tesch, 2008; Seynnes et al., 2007; Tesch, Ekberg, Lindquist, & Trieschmann, 2004). Each session trained the muscle groups involved during the upsweep phase of the arm stroke in front crawl and butterfly stroke. The work time was 15 s per set, with a total work time of 60 s. There was a 2-min break between consecutive sets. During each set, participants had to try to exercise as quickly as possible (with maximal intensity). Throughout the training period, the external loads were unchanged (19.4 kg – mass of the ITMS flywheel), but the number of stroke cycles (and movement velocity) progressively increased. Other training parameters (i.e. number of sets, set duration, and rest period) were unchanged during the training period. During training, participants received feedback in real time (the range of motion and average value of obtained force during concentric and eccentric action were displayed on the screen). Position of the participant and range of motion during training were the same as during ITMS measurements (see below). A standardized warm-up comprised 5 min of submaximal cycling on the upper body ergometer (Monark 818E, Sweden) and a few slow cycles with the ITMS were performed before each session.

Measurements

ITMS. The maximal force and power used on the ITMS were determined only for the IT group before and after the training period under the training conditions. The ITMS values were very highly reproducible (ICC consistency ≥0.971, agreement ≥0.969, ICC was tested under training conditions). The absolute error of the measurement system, consisting of the tensometer and data acquisition module, was smaller than 0.5 N. The first measurement session was preceded by two trial sessions, where swimmers learned how to perform the exercise properly. Before the maximal test, a 5-min warm-up using the arm ergometer (Monark 818, Sweden) was performed. During the test, participants *laid face down* on the stationary bench in front of the two inertial devices. Swimmer's legs were held by an assistant. The participants kept their arms along their body and flexed approximately 90° at the elbow joint. Swimmers held the handles connected to the ropes, which were fully extended and tensed (hands in pronation) (Figure 1).

During the 10-s maximal test, participants tried to imitate arm stroke upsweep phase. Swimmers were instructed to exercise as quickly as possible. During testing and training, the elbow extensor and back muscles worked concentrically during elbow extension movement (the ITMS flywheel was accelerated during this phase) and eccentrically during elbow flexion (the swimmers tried to extend their elbow throughout the exercise and elbow joint flexion was forced by the flywheel's mass of inertia). The range of motion in the elbow joint was approximately 90°. Data from the tensometer and encoder were sent to the DAQ module and saved on the computer using MAD01 software. The signal was recorded with a sampling frequency of 1000 Hz. The mean values for maximal force and power from the left and right arms were used for further analysis.

Electromyography (EMG). The electrical activity in the triceps brachii muscles was registered simultaneously with the biomechanical measurements on the ITMS. Raw EMG signals were detected using three surface electrodes (Ag/AgCl, Skintact, Austria). Before fixing the electrodes, the skin surface was cleaned and depilated. Three 15-mm-diameter surface electrodes, including one ground electrode, were placed over the central part of the triceps brachii muscle parallel to the direction of the muscle fibres with 10 mm between electrodes (Hermens et al., 1999). During the first EMG measurement, electrode placement was marked using a non-toxic pen. In every training, marked points were refreshed. Electrodes were connected to a 14-bit AD converter (ME6000 Biomonitor, Mega Electronics, Finland) by pre-amplified cables (Mega Electronics). The total common mode rejection was of 110 dB, and signal was low pass filtered using

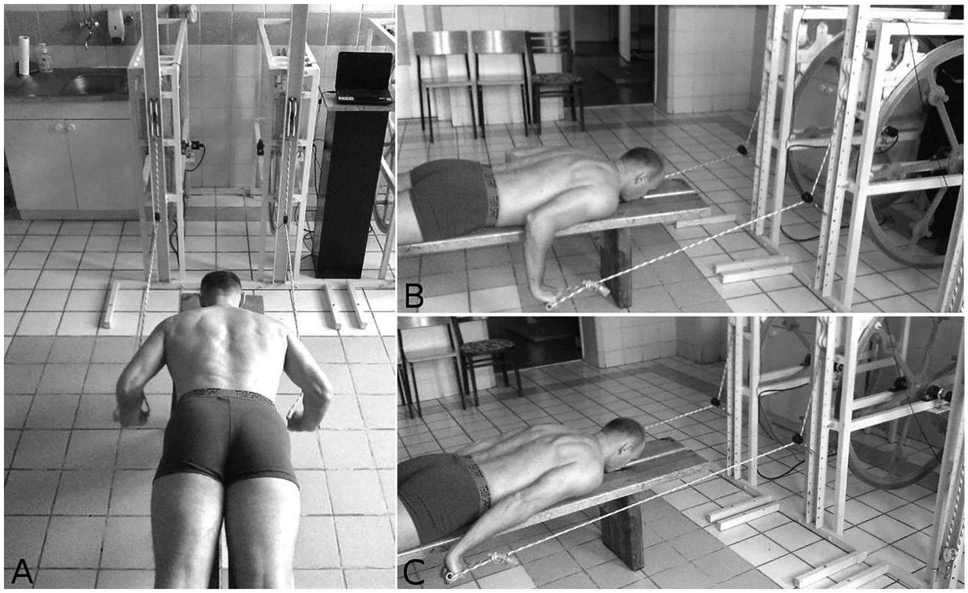

Figure 1. The position adopted during the ITMS testing and training. (a,b) Starting position; (c) ending position.

anti-aliasing filter (8–500 Hz) and then sampled at 2000 Hz before being sent to the computer. EMG data were recorded using a Biomonitor ME6000 (Mega Electronics, Finland). EMG data were analysed using Mega Electronics software (MegaWin V2.21). Only the active parts of the EMG signal were analysed based on the amplitude of the RMS EMG.

Swimming tests. Before and after IT, all swimmers underwent swimming tests. Before the tests, a 1000-m standardized warm-up was performed. After 15 min of rest, measurements were made. A 100 m butterfly and 50 m freestyle (front crawl) were performed on separate days. Swimmers made a diving start following a starter's instructions. During each test, the swimmer had to cover the distance in the shortest possible time. The swimming times of the 100 m butterfly (S100) and 50 m freestyle (S50) were measured electronically (Omega); the outcomes were: swimming times S100 and S50. Swimming tests were conducted on the same day of the week and at the same time of the day before and after training.

Muscle mass. To evaluate the influence of the ITMS training on muscle mass, bioelectrical impedance analysis (BIA, 101 Anniversary, Akern, Italy) was used before and after training. The swimmers were asked to maintain a normal state of hydration and were not allowed to exercise, eat, or drink alcohol or caffeine for 12 h preceding the measurements. Measurements were made in the morning according to the manufacturer's guidelines. The body muscle mass was estimated using Bodygram Pro software (Akern, Italy) and was expressed in kilograms.

Statistical analysis

Statistical analysis was performed using R language for statistical computing. The effects of training for each participant were defined as a relative (percentage) increase in analysed quantities, according to the formula:

$$RI[\%] = \frac{x_{\text{post}} - x_{\text{pre}}}{x_{\text{pre}}} \times 100 \qquad (1)$$

where RI is the relative increase and x is the measured value before (pre) and after (post) training.

The normality of distribution was checked with the Kolmogorov–Smirnov test and a normal distribution was found, so the parametric method of statistical description and analysis were used. Analysed data sets were described with mean values with the associated boundaries of 95% confidence intervals. These indices were presented further in the text in the following manner: mean [CI_{min} to CI_{max}] (p value). Statistical significance (type-1 error) between pre and post values of analysed parameters within group was evaluated using one-sample Welch t-test. To compare times of swimming between the control and training groups, non-paired effect sizes and additionally type-1 error levels with non-paired Welch t-test were used. The significance level was set at $p \leq .01$. For further interpretation of the effect size values, the two adequate scales were adopted: scale for Cohen's effect size (ES) presented by Rhea (2004) indicating that a $d < 0.5$ represents a small or trivial ES; 0.5–1, a moderate ES; and >0.1, a large ES, scale for Cliff's δ, presented by Macbeth, Razumiejczyk, and Ledesma (2011) the ES magnitudes are determined between −1 and 1, with −1 representing the largest negative training effect; 0, no training effect; and 1, a largest positive training effect.

Results

The absolute values of analysed parameters before and after training are presented in Table I, the effect sizes for analysed parameters are presented in Table II. After four weeks of IT, there was a 12.8% [6.41–20.12] ($p \leq .01$) increase in the muscle strength and 14.2% [9.10–20.70] ($p \leq .01$) increase in the muscle power in the IT group (ITMS conditions). Moreover, the S100 improved by −1.83% [−1.02 to −2.70] ($p \leq .01$) after IT, while, changes in the control group were significantly smaller: −0.17% [−0.73 to 0.38] ($p = .48$). Similar trends were observed for the S50, which also significantly improved in the IT group: −0.76% [−0.40 to −1.15] ($p \leq .01$), while, changes in the C group were trivial (−0.08%) [−0.78 to 0.75] ($p = .76$) (Figure 2). It is noteworthy that, in the IT group, the changes in force, power, S100, and S50 had large effect sizes, suggesting that IT is effective in young sprint swimmers. The RMS EMG of triceps brachii in the IT group increased by 22.7% [10.57–34.89] ($p \leq .01$) following training. However, muscle mass in IT group did not increase significantly after IT: 0.33% [−0.24 to 0.90] ($p = .38$).

A significant negative association was found between force and the S100 before and after training ($r = -.91$; $p = .004$ and $r = -.85$; $p = .014$, respectively). Similar trends were observed for power and the S100 (before training: $r = -.82$; $p = .023$; after training: $r = -.83$; $p = .021$). Moreover, the association between force and the S50 was significant before and after training ($r = -.92$; $p = .003$ and $r = -.86$; $p = .013$, respectively). The power registered during the ITMS testing was also associated with the S50 (before training: $r = -.83$; $p = .022$; after training: $r = -.80$; $p = .031$).

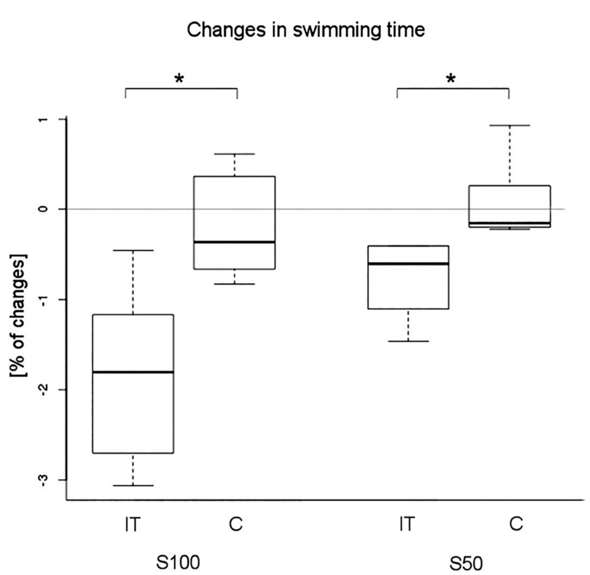

Figure 2. Changes in swimming times for the 100 m butterfly (S100) and 50 m freestyle (S50); * significant difference between the training and control group.

Discussion

Muscle force and power

Results of this study suggest that dry-land IT performed by young swimmers can be effective in improving muscle force and power (12.8% and 14.2%, respectively). Smaller improvements were noted in previous studies. Girold et al. (2007) observed a 7.5–7.8% increase in elbow extensor force (concentric conditions) in young swimmers after six weeks of dry-land strength training. Toussaint and Vervoorn (1990) noted that 10 weeks of dry-land strength training caused increases in the muscle force and power of 3.3% and 7%, respectively. However, Strass (1988) detected improvements of 20–40% in the muscle strength after a strength programme using free weights, but the training period was much longer than in the present study.

Physiological changes

Muscle force and muscle power enhancements following resistance training are usually caused by neuromuscular coordination improvement or/and muscle hypertrophy. Our present study showed that muscle force and power improvements were caused by increasing the EMG amplitude of the triceps brachii. This finding suggests that the number of active motor units, which reflects muscle activation during exercise, increased following training. Our results are in accordance with studies by Norrbrand, Pozzo, and Tesch (2010) and Seynnes et al. (2007) that confirmed that IT improved neuromuscular coordination, reflected by EMG signal changes. Moreover, IT can also lead to muscle hypertrophy (Naczk et al., 2016; Seynnes et al., 2007). However, muscle mass in our study did not change significantly following training, which may be due to the high athletic level of the tested swimmers. In both the studies cited above, untrained participants were tested.

Table I. The absolute values and standard deviations of analysed parameters.

	IT		C	
	Before training	After training	Before training	After training
Force [N]	90.7 ± 14.0	101.9 ± 15.1*	–	–
Power [W]	76.7 ± 10.7	87.5 ± 12.6*	–	–
RMS EMG [V]	0.620 ± 0.236	0.724 ± 0.193*	–	–
Muscle mass [kg]	40.2 ± 7.9	40.4 ± 8.1	–	–
S100 [s]	67.94 ± 2.66	66.70 ± 2.82*	68.34 ± 2.61	68.22 ± 2.61
S50 [s]	27.74 ± 1.06	27.52 ± 0.97*	29.38 ± 1.05	29.35 ± 0.95

Abbreviations: S100: 100 m butterfly swimming time; S50: 50 m front crawl swimming time.
* Significant difference from pre-test to post-test.

Swimming performance

Although the results of this and other studies indicated that strength training could be effective in enhancing muscle force and power in swimmers, there are conflicting reports on the effect on swimming performance. Tanaka et al. (1993) reported that eight weeks' strength training caused increases of 25–35% in muscular strength, but the sprint swimming times did not change. Similar findings were presented by Sawdon-Bea and Benson (2015); dry-land strength training was effective in improving core strength; however, swim performance remained unchanged. This is consistent with Trappe and Pearson's (1994) suggestions, who stated that dry-land strength-assisted training did not provide an advantage as compared to free-weight training, or a disadvantage when applied to front crawl swimming. On the other hand, Girold et al. (2007) noted that elbow extensor strength and swimming velocity improved significantly (25.4% and 2.8%, respectively) following 12 weeks of dry-land strength training. Improvements in swimming tests were also noted in water polo players following six weeks of dry-land strength training (Saez de Villarreal, Suarez-Arrones, Requena, Haff, & Ramos-Veliz, 2014). Positive influence of dry-land resistance training was observed by Sadowski, Mastalerz, Gromisz, Jowko, and Buszta (2015), and the authors suggest that the experimental group demonstrates greater improvement in sprint performance than the control. Two weekly dry-land strength training sessions for 11 weeks increase tethered swimming force and middle distance swimming performance in competitive swimmers (Aspenes, Kjendlie, Hoff, & Helgerud, 2009).

Our study shows that improvements in muscle force and power noted in IT can positively influence swimming performance. It is possible that IT can give greater benefits than traditional strength training in swimming practice, but future studies are needed to test this hypothesis. This suggestion is consistent with that of the study of Onambele et al. (2008), where IT produced a greater increase in peak power than weight training. Greater increases in muscle power can result from greater muscle stimulation during inertial vs. weight training (Norrbrand et al., 2008, 2010). The great improvement in swimming time noted in our study (IT) in a relatively short time period is surprising. Participants were young, but they were national-level competitive swimmers and their swimming training volume was quite great (about 19 h per week); therefore, we believed that the improvement in swimming performances would be smaller. Obviously, the small amount of participants (a limitation of this study) could influence the results. The high effectiveness of short-term IT on enhancing muscle force and power was reported by Brzenczek-Owczarzak et al. (2013), Naczk et al.

Table II. The effect sizes for some analysed parameters.

	IT_{ES}			C_{ES}		
	d	CI_{min}-CI_{max}	δ	D	CI_{min}–CI_{max}	δ
Force	2.26	0.81–3.71	1	–	–	–
Power	3.06	1.39–4.72	1	–	–	–
S100	2.70	1.13–4.26	1	0.38	−0.72–1.48	0.14
S50	2.50	0.93–4.00	1	0.15	−0.94–1.24	0.08

Abbreviations: S100: 100 m butterfly swimming time; S50: 50 m front crawl swimming time; IT_{ES} and C_{ES}: effect sizes in the IT and control groups, respectively; d: Cohen value; CI_{min}: lower border of 95% confidence interval for d; CI_{max}: upper border of 95% confidence interval for d; δ: one-sample Cliff's dominance probability.

(2014), Seynnes et al. (2007), and Tesch et al. (2004); however, these authors did not evaluate a practical application. In Naczk et al. study (2016), authors showed that five weeks of ITMS training in young physically active men induced significant increases in knee extensor force (25.2%) and power (33.2%), and these improvements were also transferred to other movement patterns. The effectiveness of IT in sport practice (baseball) has only been confirmed by Davison et al. (2010), but the training and testing were done in the same environment. We suppose that the transfer of force and power (gained following IT) to swimming performance could be caused by the specific movement pattern used in ITMS (swimmers imitated upsweep phases). This is supported by Fleck and Kraemer (2004) who stated that strength training programme should include the types of muscle actions encountered in that sport activity. Likewise, Young (2006) determined that training should be as specific as possible to maximize the transfer to specific sport skills, especially with regard to the movement pattern. Additionally, Brandon (2002) found that effects are greatest when swimmers follow a programme of exercises that replicates their actions in the water as closely as possible. Moreover, Wilson, Murphy, and Walshe (1996) highlighted that strength training activities that are performed in a similar posture to that of the specific sport tend to lead to the greatest improvement. Inertial training performed by IT group in our study met these criteria.

Moreover, placebo effect in IT should not be excluded. Before experiment, all participants were informed that IT is highly effective in untrained participants and it is highly likely that this training will be also effective in swimming practice. Kalasountas, Reed, and Fitzpatrick's (2007) study showed that placebo effect can lead to significant increase in the muscle strength estimated by one repetition maximum. On other hand, Wright et al. (2009) showed that placebo effect may be of significant magnitude in endurance exercises but do not change muscle power.

It is known that as athletes become more trained, it becomes more difficult to stimulate performance gains. Thus, increased variation is often required in the training programme (Haff & Triplett, 2016). It is also possible that IT was a positive variation in training regime and could hit a plateau.

Associations between muscle strength, power, and swimming performance

It is interesting that the values of parameters registered while using the ITMS (force and power) negatively correlated with swimming times (S100 and S50). These results suggest that the muscle force and power reached using the ITMS are related with sprint swimming performance. It is consistent with Morais et al. (2016) who stated that strength and power output parameters do play a mediator and meaningful role in the young swimmers' performance.

Moreover, Garrido, Marinho, Barbosa, et al. (2010) study revealed significant association of bench presses, leg extension exercises, and throwing power tests with sprint swimming performance in young competitive swimmers ($r > -.54$). Similar conclusion was demonstrated by Morouço et al. (2011), lat pull down back results were associated with sprint swimming velocity in 15-year-old national-level swimmers ($r = .68$). These authors demonstrated that between results of dry-land tests (bench press, lat pull down back) and force values achieved during the 30 s swimming test, a significant correlation occurred (r ranged from .65 to .73).

Limitation of this study

Unfortunately, swimmers from the control group participated only in swimming tests; their parents did not give consent for their children participation in laboratory tests. Another limitation of the study was the relatively small sample size – it was highly difficult to collect a large group of swimmers on a similar, high level of sports.

Conclusions

The results of this study suggest that IT can be useful in swimming practice. We recommend to test this suggestion in a large group of swimmers, including a control group. The short-term IT can lead to significant increases in muscle force and power in young elite swimmers. Moreover, the swimming times in the 100 m butterfly and 50 m freestyle events improved significantly in group of swimmers who performed dry-land IT for four weeks but remained unchanged in the control group. Strength testing using the ITMS can be a good tool to predict sprint swimming performance.

Acknowledgements

We thank all the swimmers who participated in this study; we appreciate that you trained as hard as possible, every time.

Disclosure statement

No potential conflict of interest was reported by the authors.

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