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Resistance Training in Health and Sports Performance

Transfer of Dry-Land Resistance Training Modalities to Swimming Performance

by

Jerzy Sadowski[1], *Andrzej Mastalerz*[2], *Wilhelm Gromisz*[1]

A great number of studies focusing on the effects of dry-land resistance training interventions on swimming performance remain inconclusive. It is suggested that transferability of dry-land strength gains to swimming performance appear when dry-land resistance training programs are swim-specific. The main aim of this study was to compare the effects of specific dry-land resistance training on an ergometer with traditional dry-land exercises, and to determine how much of the resistance training effects were transferred to specific swimming conditions. The study included a group of 26 youth competitive male swimmers (age 15.7 ± 0.5 years, height 174.6 ± 6.6 cm, weight 68.4 ± 8.2 kg, training experience 5.8±0.7 years) of regional level. They were randomly allocated to one of two groups: experimental (E) and control (T). Both groups were involved in a 12-week dry-land resistance training concentrated on increasing muscular strength and power output of the upper limbs. Group E used a specialized ergometer (JBA – Zbigniew Staniak), while group T performed traditional resistance exercises. The program consisted of 10 sets of 30 s of exercise with 30 s rest intervals between each set. A two-way repeated measures ANOVA with Tukey HSD post hoc comparisons was used to determine if any significant differences existed between training groups across pretest and posttest conditions. The significance level was set at p ≤ 0.05. Dry-land resistance training modalities were the only differences in training between both groups. Our findings show that rates of transfer are much higher in group E than in group T, which resulted in a significant increase in swimming velocity (by 4.32%, p<0.001; ES=1.23, and 2.78%, p<0.003, ES=0.31, respectively).

Key words: *swimmers, front crawl, strength, power output, ergometer.*

Introduction

Swimming performance is highly dependent on muscular strength and power output (Amaro et al., 2016; Aspenes and Karslen, 2012; Barbosa et al., 2013; Girold et al., 2007; West et al., 2011). Previous research has found strong correlations between dry-land resistance exercises and swimming performance (Aspenes et al., 2009; Garrido et al., 2010; Morouco et al., 2011; Tanaka and Swensen, 1998). Morouco et al. (2011) stated that the latissimus pull-down has strong correlations with swimming performance. Keiner et al. (2015) reported that a 1 repetition maximum (RM) parallel squat, bent-over row and bench press positively correlate with swimming performance. Similar research results are reported by Garrido et al. (2010) and West et al. (2011).

Garrido et al. (2010) examined the relationship between the bench press and leg extension exercises and showed a moderate correlation with 25 m and 50 m swimming performance tests (r = 0.58 to 0.69). Also, West et al. (2011) found a significant correlation (r = 0.74) between the 1RM back squat and 15m swimming performance. Specifically, significant correlations between upper-body muscular strength and power output and swimming velocity were shown over sprint distances (Aspenes et al., 2009; Toussaint and Vervoorn, 1990). This seems obvious since the upper body musculature

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[1] - *Faculty of Physical Education and Health, Jozef Pilsudski Academy of Physical Education in Warsaw, Warsaw, Poland.*
[2] - *Faculty of Physical Education, Jozef Pilsudski Academy of Physical Education in Warsaw, Warsaw, Poland.*

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generates the majority of propulsive forces during swimming (Bucher, 1975;Morais et al., 2018). Not surprisingly, resistance training is common training method for the development of muscular strength and power in swimming (Muniz-Pardos et al., 2019, 2020). Consequently, swimming coaches implement various RT modalities: 1) swim-specific resistance training, 2) dry-land resistance training (DLRT) to overload the muscles used in swimming and increase maximal power output. The implementation of dry-land resistance training interventions demonstrated a significant gain in strength and power output on land but that improvement was not transferred to the propulsive forces in water conditions (Tanaka and Swensen, 1998).

Nevertheless, several researchers have found positive transfer (Aspenes et al., 2009; Girold et al., 2007, 2012; Morais et al., 2018; Strass, 1988) to swimming performance after a DLRT program intervention. For instance, Girold et al. (2012) found a 2% increase in 50 m performance after DLRT. Similarly, Strass (1988), Girold et al. (2007), and Morais et al. (2018) reported an increase in swimming performance by 2.1% ($p<0.01$), 2.8% ($p<0.05$) and 3.77% ($p<0.001$), respectively. By contrast, Aspenes et al. (2009) showed a 20.3% improvement in dry-land strength but this gain did not transfer to improvements in 50 m and 100 m swimming performance. Also, Tanaka and Swensen (1998) showed that strength increases of 27-35% did not significantly transfer to swimming performance. The studies by Song et al. (2009) and Manning et al. (1986) provided further evidence that application of traditional dry-land resistance programs induced an increase in strength but did not transfer to swimming performance. A low transfer from land to water may stem from different modalities of DLRT used in some studies. e.g., traditional weight training (Aspenes et al., 2009; Girold et al., 2007, 2012; Song et al., 2009), core training (Weston et al., 2015), biokinetic swim bench (Roberts et al., 1991), and resistance-band training (Girold et al., 2006).

Despite a great deal of studies focusing on the effects of DLRT interventions on swimming performance, results remain inconclusive. It is suggested that transferability of dry-land strength gains to swimming velocity appear when the DLRT program is swim-specific (Crowley et al., 2017; Goodwin and Cleather, 2016; Tanaka and Swensen, 1998). Trainable characteristics such as muscular strength, power output and other factors of motor performance are specific to the stimulus (training means) applied. To increase the positive transfer of strength gains to swimming performance, DLRT should be similar in various aspects, including muscular activity during the exercise, movement patterns performed, the range of motion and joint angles of the exercises, and stroke frequencies similar to swimming performance (Goodwin and Cleather, 2016). The DLRT program should mimic the in-water movements as much as possible (Amaro et al., 2016). Unfortunately, it is difficult to design DLRT exercises that meet all the recommendations for specificity.

Some researchers reported that movements performed when swimming such as water drag are difficult to replicate in dry-land exercises (Bucher, 1975; Strass, 1988; Tanaka and Swensen, 1998). Therefore, greater specificity within DLRT is needed.

The above mentioned research suggests that dry-land training that meets most of the recommendations for specificity would be more efficient than traditional dry-land training incorporating various resistance exercises. To our knowledge, no studies have compared the transfer of different DLRT modalities to swimming conditions. Therefore, the main aim of this study was to compare the effects of specific dry-land resistance training on an ergometer with traditional dry-land resistance training and to determine how much of the resistance training effects were transferred to specific swimming conditions. It was hypothesized that greater specificity within the DLRT program would lead to greater transfer of resistance training effects than traditional dry-land training.

Methods

Subjects

The study included a group of 26 youth competitive male swimmers (mean ± SD; age 15.7 ± 0.5 years, height 174.6 ± 6.6 cm, weight 68.4 ± 8.2 kg) of regional level. They were randomly allocated to one of two groups: experimental (E) (n = 12, age 15.8 ± 0.4 years, height 175.7 ± 5.9 cm, weight 67.8 ± 7.9 kg) and control (T) (n = 14, age 15.6 ± 0.6 years, height 173.4 ± 7.1 cm, weight

69.1±8.4 kg). All swimmers were sprinters, i.e., 50 m and 100 m front crawl specialists, who trained an average of 12 ± 1.5 hours per week. They had a minimum of 5 to 7 years of training experience. The participants were instructed to maintain their normal dietary habits over the entire study period. The subjects' parents signed an informed consent form and the swimmers participated in the study on a voluntary basis. This study was approved by the Institutional Review Board and University Ethics Committee. The analysis included only those swimmers who completed the whole program.

Training device

A "hydroisokinetic" ergometer (Sadowski et al., 2012) was applied during the DLRT sessions (Figure 1). This ergometer simulates the underwater phase of shoulder movement during the front crawl. The ergometer has a base frame made of stainless steel with a screw mechanism for mounting on the edge of a swimming pool. During training, each subject lay prone on a bench, assuming the same body position held during swimming.

The tested subject drives the ergometer by holding handles connected to a rotary head equipped with blades with a freely adjustable geometry (1). During the exercise session, the forces and stroke lengths of the motions of the right and left arm are measured. A two-component force transducer (3) is used to estimate the force during control measurements, as well as during the training session. The length of each stroke is measured using a potentiometer (2) located along the axis of the rotating head.

Training procedure

Swimming training

The swimming training program was the same for both groups and consisted of 11 sessions of 1 hour 30 minutes per week (from Monday to Saturday). The training was performed in a 25 m pool. Before each training session, the subjects performed a standardized warm-up for 15 minutes. The training program lasted from September to December, and represented the first macrocycle of the season. The swimmers were preparing for their regional championships that were held in December. Average training load (volume and intensity) was similar for both groups throughout the study. Characteristics of training loads are presented in Table 1.

The average total distance of 546.9 km was covered during the whole experiment by each subject. To determine the training intensity, heart rate (HR) was monitored.

Design of DLRT

Both groups were involved in dry-land resistance training. The DLRT program was directed at increasing muscular strength and power of the upper limbs. The swimmers from group E used a specialized ergometer, while group T performed traditional resistance exercises. The DLRT sessions lasted 12 weeks (122 training sessions) and they were performed 3 times a week (Monday, Wednesday, Friday) and preceded swim training. The DLRT consisted of 10 sets of 30 s of exercise with 30 s rest intervals between each set. During each DLRT session, the subjects from group E practiced with the frequency of approximately 50-60 strokes/minute. The resistance load was increased whenever the swimmer could perform more than 60 strokes/minute. To increase exercise intensity, the geometry of the blades in the water were adjusted as needed to obtain efficient resistance. The swimmers from group T practiced on a traditional dry-land resistance circuit consisting of various upper body exercises (bench press, backward arm press, horizontal row, supine straight-arm pullover, and dips) that show positive relationships with swimming performance. In each DLRT session, the program of group T was the same. This circuit was repeated twice per session. The subjects were asked to repeat each exercise with maximal movement tempo (Wilk et al., 2020a). Before each DLRT session, a standardized warm-up of 15 minutes was administered. The DLRT modalities described above were the only differences in training between both groups.

Test procedures

The baseline measurements took place before the commencement of the training program and the final evaluations took place after 12 weeks of combined swimming and DLRT. The evaluations included the following assessments:

- the assessment of isometric strength (IS),
- the assessment of swimming performance during the front crawl driven by the upper arms over 25 m (V25),
- the assessment of strength during tethered swimming (TS),

- the measurement of isometric strength (IS) conducted on an ergometer (Figure 1).

Two 5-s measurements of shoulder flexion with arms adjusted at the angles of 90° and 135° between arms and trunk were also performed. The greatest value of IS was chosen for analysis. The signals were captured at 400 Hz by a computer interface and stored in a data acquisition program for later analysis.

One day after IS tests, the swimmers performed a 25 m free style time trial. Stroke length (SL) and stroke frequency (SF) were determined with video recording using a Sony HDR-CX 130 camcorder. Screenshots were taken from the video recording using Kinovea System® software to measure SL and SF. Speed of locomotion was defined as a product of stroke frequency and stroke length and was defined through the time of stroke cycle T:

$$V = \frac{SL}{T} = \frac{SL \times SF}{60}$$

The equation (1) for the distance per stroke (SD) is presented below:

$$SL = V \times T = \frac{60 \times V}{SF}$$

The tethered swimming force was determined in two incremental tests with the swimmers connected to a 1,000 N load cell with 4 strain gauges attached with a commercial elastic cord (Strech Cordz Long Belt Slider (12–31 lb), NZ Manufacturing, Inc., USA). Strength was evaluated in tests over 10 s (TS). The signals were captured at 400 Hz by a computer interface and stored in the data acquisition program.

Validity of testing on the ergometer, tethered swimming force and swimming velocity were established on the prediction of interclass correlation (ICC) obtained during testing measurements conducted twice before the experiment on the whole group. The interclass correlation coefficients were good (0.861 for F90, 0.871 for F135, 0.815 for Fw and 0.701 for V).

Statistical analysis

The sample size for the current study was guided by the sample sizes and analyses of similar studies, including Girold et al. (2007, n = 21), Aspenes et al.(2009, n = 20), Morais et al. (2018, n = 27). The sample size calculations were established on the average effect sizes for (ES) changes in the magnitude of strength transfer to velocity and strength in water. An ES estimate of 0.67 was calculated from previous data in healthy youth swimmers (Sadowski et al., 2012). An a priori sample size calculation for the between factorial ANOVA using a repeated measures design with predicted ES (0.67) power (1-β) = 0.80, $p = 0.05$ was determined using G*Power v. 3.1.9.4 (Faul et al., 2007). It was determined that a minimum of 18 participants (9 per group) for the primary measure for force and 12 (6 per group) participants for primary measure of velocity were required. A sample of 26 participants (12 and 14 in each group) was considered appropriate to detect statisticaly significant differences at the recommended 0.80 level.

Means and standard deviations (SD) were used to represent centrality and spread of the data; all variables were also assessed for normality (Shapiro-Wilk test). A one-way ANOVA was used to test for differences in the initial values between groups for all dependent variables. A two-way repeated measures ANOVA with Tukey HSD post hoc comparisons was used to determine if significant differences existed between training groups across pretest and posttest conditions. The significance level was set at $p \leq 0.05$.To determine the magnitude of differences between the groups, partial eta squared (ηp^2) was calculated for multiple comparisons (.01 small; .06 moderate; .14 large) and Cohen's ES was calculated for pairwise comparisons (0.25 small; 0.5 moderate; 0.8 large) (Cohen, 1992).

The data were analyzed using Statistica v.13.1 software for ANOVA analysis. The magnitude of gain after DLRT was calculated according to the following formula:

$$Gain = \frac{Post - Pre}{Pre}$$

The magnitude of transfer known as the "transfer effect coefficient" was calculated according to an equation:

$$Transfer = \frac{Untrained \ \% \ Gain}{Trained \ \% \ Gain}$$

Results

All data are reported in Table 2. The one-way ANOVA revealed insignificant differences between the tested groups in the initial values (pretest): F90 (F(1. 24) = 0.149; $p = 0.702$); $\eta p^2 = 0.006$), F135 (F(1. 24) = 0.355; $p = 0.556$; $\eta p^2 = 0.015$), Fw (F(1. 24) = 4.087; $p = 0.054$; $\eta p^2 = 0.145$), and V (F(1. 24) = 1.012; $p = 0.324$; $\eta p^2 = 0.041$).

ANOVA with repeated measures confirmed a significant increase in: F90 (F(1. 24) = 126.114; $p<0.001$; $\eta p^2 = 0.84$), F135 (F(1. 24) = 41.594; $p<0.001$; $\eta p^2 = 0.63$), Fw (F(1. 24) = 61.269; $p<0.001$; $\eta p^2 = 0.72$), and V (F(1. 24) = 47.258; $p<0.001$; $\eta p^2 = 0.66$). Post hoc Tukey HSD test showed significant differences for all gains between posttest and pretest except F135 in T group (Table 3). Posttest results of F90 ($p = 0.875$), F135 ($p = 0.412$) and V ($p = 0.457$) were insignificantly higher in group E. A significant difference from pretest was proved only in Fw ($p<0.05$).

Effect sizes and percentage increases for Fw, V, F90 and F135 (except ES for F90) were greater in the E group in comparison to the T group following the training period (Table 2).

Transfer of training effects was calculated in two ways. In the first case, the result improvement was calculated based on the mean gain of performance and standard deviation of the group, and in the second case, we used the individual improvement of performance and the standard deviation of the group (Table 3). The second method allowed us to use ANOVA to determine intergroup differences. The one-way ANOVA revealed significant differences between the tested groups. Transfer of training effects reported in group E was significantly higher in V to F90 (F(1, 24) = 6.680; $p<0.01$), and V to F135 (F(1, 24) = 36.639; $p<0.001$). Both transfer effects from Fw to F90 (F(1, 24) = 0.779; $p = 0.386$) and Fw to F135 (F(1, 24) = 0.827; $p = 0.372$) were insignificantly higher in group E.

The results presented in Tables 1 and 2 show that the transfer is effective in improving all measured data. However, the transfer of training effects was higher for all data gains reported in group E.

In Table 4, we estimated the changes of stroke length and stroke rate in both groups. The increase in V should be attributed to the increase in SR in group T and LC in group E.

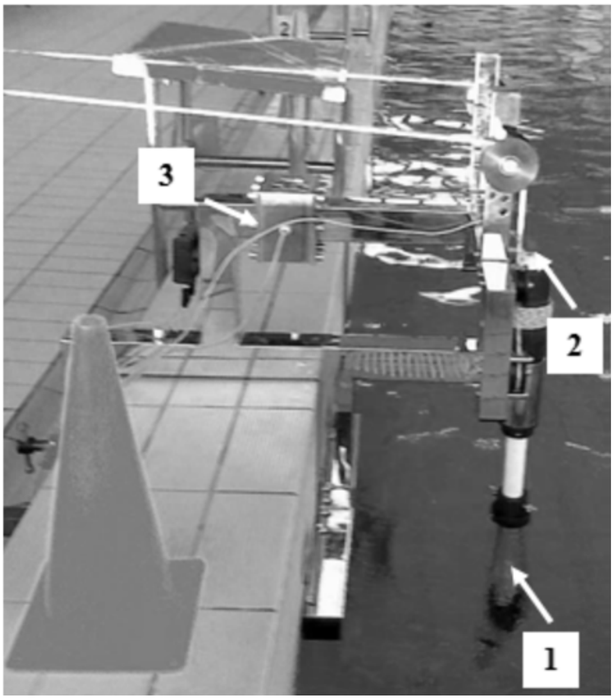

Figure 1

The ergometer applied during the experiment.

Table 1

Characteristics of training loads in particular energy zones

	Aerobic 2, EN1	Mix zone 3, EN2-3	Anaerobic zone 4, SP1-2	Sprint zone 5, SP3
Distance [km]	546.9	67.9	16.7	8.3
[%]	83.02	12.42	3.05	1.51

Table 2

Absolute results, gains, effect size (ES) and percentage increases (SS) for each variable after 12 weeks of experimental (E) and traditional (T) resistance training.

Group	Variable	Pre-test	Post-test	Performance improvement	ES	SS [%]
E	F90 [N]	241.39 ± 64.72	271.62 ± 64.18	30.23 ± 12.77	0.47	12.52
				$p<0.001$		
	F135 [N]	257.45 ± 66.98	297.67 ± 76.05	40.22 ± 21.15	0.56	15.62
				$p<0.001$		
	Fw [N]	151.33 ± 30.71	168.5 ± 29.18	17.17 ± 10.89	0.57	11.35
				$p<0.001$		
	V [m/s]	1.85 ± 0.06	1.93 ± 0.07	0.08 ± 0.04	1.23	4.32
				$p<0.001$		
T	F90 [N]	233.64 ± 35.3	256.17 ± 32.85	22.54 ± 11.2	0.66	9.64
				$p<0.001$		
	F135 [N]	244.54 ± 42.39	260.8 ± 41.47	16.26 ± 23.16	0.39	6.65
				$p = 0.053$		
	Fw [N]	131.9 ± 17.44	141.8 ± 19.74	9.9 ± 6.51	0.53	7.51
				$p<0.002$		
	V [m/s]	1.8 ± 0.16	1.85 ± 0.16	0.05 ± 0.06	0.31	2.78
				$p<0.003$		

Table 3

Transfer effects for each variable after 12 weeks of experimental (E) and traditional (T) resistance training.

Group		Fw-F90	Fw-F135	V-F90	V-F135
E	Transfer (group data)	1.20	0.93	3.11	2.42
T	Transfer (group data)	1.12	0.68	2.01	1.21
E	Transfer (individual data)	1.487	1.187	1.487	2.882
T	Transfer (individual data)	0.952	0.723	0.456	0.327

Table 4

Absolute results, effect size (ES) and percentage increases (SS) in stroke frequency (SF) and stroke length (SL) following 12 weeks of experimental (E) and traditional (T) resistance training.

Group		Pre-test	Post-test	ES	SS [%]
E	SF [cycles · min^{-1}]	1.08 ± 0.04	1.08 ± 0.06	0.04	0.19
	SL [m]	1.71 ± 0.06	1.79 ± 0.11	0.90	4.68
T	SF [cycles · min^{-1}]	1.13 ± 0.13	1.17 ± 0.14	0.25	3.16
	SL [m]	1.61 ± 0.18	1.59 ± 0.19	-0.11	-1.24

Discussion

The aim of this investigation was to explore the transfer of DLRT modalities to swimming performance in regional youth swimmers. The main results showed that 12 weeks of DLRT induced significant gains in dry-land fitness evaluations. Compared to initial values (pretest), results of isometric testing with the arm at 90° and 135° positions increased by 12.52% and 15.6% in group E, while in group T, by 9.64% and 6.65%, respectively. The reason for these differences may be the different resistance training protocols of DLRT applied in both groups. These data are in agreement with previous studies (Aspenes et al.,2009; Song et al., 2009; Strass et al., 1988; Manning et al., 1986) showing an improvement in strength following the designed dry-land training. From the presented results, it was expected that dry-land strength gains would lead to higher levels of in-water force exertion and swimming velocity. We found that 12-week DLRT resulted in significant improvements in force in water in groups E and T. Group E had DLRT on the ergometer, which may have led to higher specificity and a greater positive influence on swimming velocity in comparison to group T. These data suggest that a specific DLRT program would lead to greater transfer of resistance training effects compared to traditional dry-land circuit training. Amaro et al. (2016) suggested that a positive transfer of dry-land strength gains to swimming occurs when resistance training improves muscle activation patterns and biomechanics (kinematics and kinetics) required in swimming performance. It is a well known fact that resistance training elicits neuromuscular adaptations which are specific to the type of stimulus (Zajac et al., 2015, Wilk et al., 2018, Wilk et al., 2020b,c). The need for specificity within DLRT has been mentioned in many studies (Aspenes et al., 2009; Girold et al., 2007; Manning et al., 1986). By using the ergometer in group E during DLRT sessions, we partly met the criteria of the specificity of front crawl swimming performance (e.g., similar stroke frequencies, the range of motion, postural position, muscle activity during the exercise). Taking these factors into consideration, along with the Dynamic Correspondence Theory (Godwin and Cleather, 2016) guidelines for designing resistance training, we suggest that specific resistance training exercises that mimic swimming performance enhance the transfer of training to swimming performance. Further support for this assumption comes from the comparison of the magnitude of transfer in both groups (Tables 2 and 3). It is worth noting that the rates of transfer are much higher in group E than in group T, which resulted in a significant increase in swimming velocity (by 4.32% and 2.78%, respectively). Swimming velocity depends on SL and SF (Crowley et al.,2017). Stroke frequency was determined as the most important factor in 50 m swimming performance (Girold et al., 2007). Coaches have attempted to find the optimal relationship between these technical variables.

This study showed that in group E, DLRT with imposed frequency of up to 60 strokes/minute (similar to swimming) allowed the swimmers to increase SL, while group T practicing with self-regulated maximum frequency demonstrated an increase in SF and a decrease in SL. In previous studies, a decrease in swimming velocity was demonstrated with a decrease in stroke length (Craig et al., 1985). In contrast, an improvement in stroke length transferred to an increase in swimming velocity (Girold et al., 2012; Morais et al., 2018; Strass,1988). On the other hand, Dragunas (2012) found an increase in SL but he did not register any improvements in swimming performance. The research by Tanaka and Swensen (1988) demonstrated that an increase in resistance-training performance did not result in an increase in SL. To date, the results of transferability of DLRT to SL and SF are rather inconclusive. This study suggests that practicing with frequency typical of swimming events is needed for improving SL without decreasing SF.

The findings of this study highlight the benefits of DLRT in terms of swimming velocity. Despite the fact that traditional resistance training programs are not specific to swimming performance, coaches propose the inclusion of DLRT to improve swimmers' power and strength. The results of such practices show that an increase in land strength did not transfer to swimming performance.

The design of our study was based on the suggestion that DLRT should be swim-specific to enhance transfer to swimming performance. The results of DLRT on the ergometer confirmed a significantly higher transfer to swimming performance than traditional resistance training.

The limitation of this study is the regional sports level of the participants and the lack of monitoring muscle activity during DLRT.

Future research is required to explore the transfer of DLRT modalities to swimming performance and to monitor muscle activity during resistance training in competitive swimmers.

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Corresponding author:

Jerzy Sadowski
Faculty of Physical Education and Health,
Jozef Pilsudski Academy of Physical Education in Warsaw, Warsaw, Poland
34 Marymoncka Street
00-968 Warszawa
E-mail: jerzy.sadowski@awf-bp.edu.pl