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EFFECT OF DRY-LAND STRENGTH TRAINING ON SWIMMING PERFORMANCE: A SYSTEMATIC REVIEW

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SUMMARY

The aim of this study was to consolidate as many studies as possible and draw a general conclusion about the effects of dry-land strength and conditioning training on swimming performance. Accordingly, 16 studies were analyzed. Of that number, 14 studies looked at the direct effect of additional dryland strength training on swimming performance. One of them examined the effect of additional strength training on dry land on the swimming performance of Paralympic swimmers. Of the remaining 2 studies, one study examined the effect of additional dryland strength training on swimming turns, while the other examined the effect of additional dryland strength training on starting blocks. As a general conclusion of the study, we conclude that additional strength training on dry land has a positive effect on swimming performance, regardless of variable factors in terms of the type of training, age, gender and swimming level of the subject, if it is properly designed and implemented in practice. This conclusion came from the results of 12 analyzed studies in which a statistically significant improvement in swimming performance was recorded. In the 4 remaining studies, there was also a tendency to improve swimming performance or an improvement in some of the swimming performance, but this improvement in performance was not statistically significant, or the improvement in ability did not lead to an improvement in the final swimming performance.

Key words: effect, dry-land training, swimming performance

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INTRODUCTION

Strength, as a basic motor ability, has recently been considered a multi-factorial phenomenon that improves swimming performance (Barbosa, Bragada, Reis, Marinho, Carvalho, et al., 2010). This is supported by the results of the study by Morouço, Keskinen, Vilas-Boas & Fernandes (2011), which show that the production of force in the water, which largely depends on the level of strength, is one of the decisive factors for success in swimming. However, although today we can say with certainty that strength is essential for success in swimming (Garrido, Marinho, Barbosa, Costa, Silva, et al., 2010), it is unknown whether the increase in strength achieved by strength training on dry land affects swimming performance.

Different studies, which were engaged in researching this topic, gave very different results. One of the studies (Aspenes, Kjendlie, Hoff & Helgerud, 2009) showed that there are positive effects of additional strength training on dry land on swimming performance, precisely in the form of greater force production during swimming, which ultimately led to better results. However, the increase in force production during swimming influenced the improvement of the final result only in disciplines of middle distance (400 m). In the sprint events (50 m and 100 m), additional strength training on dry land did not cause statistically significant changes. On the other hand, there are studies that have shown that there are positive effects of additional strength training on dry land on swimming performance and in the 50 m sprint event (Girold, Maurin, Dugue, Chatard & Millet, 2007; Strass, 1988; Pichon & Chatard, 1995). Some of the studies, however, show that there is no statistically significant effect of additional strength training on dry land on swimming ability and final result in swimming (Tanaka, Costill, Thomas, Fink & Widrick, 1993). Also, there are those undecided studies, based on the results of which it cannot be asserted with certainty that additional strength training on dry-land caused positive effects on swimming performance (Lopes, et al., 2021; Sadowski, Mastalerz, Gromisz & NiŸnikowski, 2012; Garrido, Marinho, Reis, van den Tillaar, Costa, et al., 2010).

However, all these studies, although they dealt with the same topic, are very different from each other. These differences are reflected in the samples of the respondents (their age, gender, level of swimming technique, level of sports fitness, etc.), as well as the application of different methods and types of strength training on dry land (with different training equipment, different duration of the training program, different volume and load intensity). The parameters that were tested in these studies were also different, both in the form of disciplines and in the form of swimming technique parameters to which the results were related. Therefore this study aimed to consolidate as many studies as possible and draw a general conclusion about the effects of dry-land strength and conditioning training on swimming performance.

METHODS

An extensive literature search was conducted to identify studies from January 1st, 2011 until December 31st, 2021 in which strength training programs effects on swimming were investigated. Google Scholar, Scopus and PubMed databases were used to collect data on the effect of dry-land strength training on swimming performance. Also, the references of all papers that were taken into account were reviewed, with the aim of reaching as many works as possible that dealt with the research of this topic.

During the search, the following keywords were used: effect, influence, dry-land strength training, swimming performance, relationship/influence/effects, between/ of, dry-land strength training, and/on, swimming performance.

Review articles (qualitative review, systematic review, and meta-analysis) were not considered. The included studies focused on longitudinal interventions in strength and conditioning training on competitive swimming. Also, studies witch written in English and their main outcome reported was a swimming performance measure (e.g. time or velocity).Studies that did not present a complete description of their methods and/or results were excluded, also studies where the sample of respondents was not competitive level.

RESULTS

Tables 1 show the purpose, sample characteristics, strength and conditioning training program, swimming performance measures and relevant findings. Based on the keywords, the search yielded 7165 papers. Of this total number of documents, 356 were eliminated because they represented systematic reviewed research. After reviewing 173 papers, and reading their abstracts, conclusions and results for the final analysis, 16 papers were singled out that met all the necessary conditions.

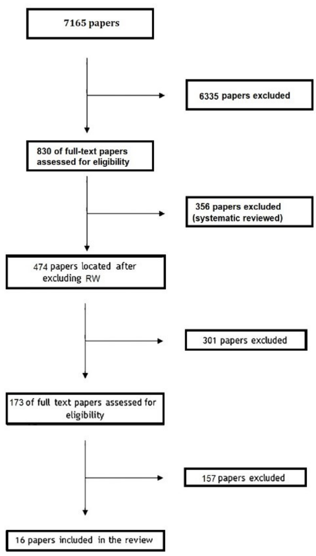

Figure 1 Flow of information through the different phases of paper selection for the systematic review

All papers considered for detailed analysis were published between 2011 and 2021. Also, in each of them, the effect of strength training on dry land on swimming performance was examined experimentally.

Samples size ranged from 7 (Dingley, Pyne, Youngson, & Burkett, 2015) to 60 (Pesic, Okičić, Madić, Dopsaj, Djurovic, et al. 2016). The most frequent number of respondents was between 20 and 30 (in 9 analyzed studies). In 6 of the analyzed studies, the number of respondents was less than 20, while in only one (Pesic, et al. 2016) this number was greater than 30. When it comes to the gender of the respondents, in 9 of the analyzed studies, the sample consisted of members of both half. The sample consisted of only male members in 6 analyzed studies, while in only 1 study the sample consisted of only female members (Popovici & Suciu, 2013). When it comes to age, the youngest respondents were 10 years old (Pesic, et al. 2016), while the oldest were 21.89 ± 3.41 years old (Rejman, Bilewski, Szczepan, Klarowicz, Rudnik, et al. 2017). In 6 analyzed studies, the sample consisted of adult respondents (over 19 years old). Adolescents (10-19 years) made up the sample in 10 analyzed studies, while there were no pre-puberty respondents. When it comes to dividing respondents into groups, in the largest number of surveys, there were 2 groups (8 surveys). The smallest number of groups was 1 (in 4 analyzed studies), while the largest number of groups was 4 (Pesic, et al. 2016). In addition to the aforementioned, in 3 analyzed studies, the number of groups was 3. When it comes to experience, in 14 analyzed studies the sample consisted of experienced swimmers with competitive experience, in 1 study (Yapıcı-Öksüzoğlu, 2020) the sample consisted of recreational swimmers swimmers, and also in 1 (Sadowski, Mastalerz, Gromisz, Jówko, & Buszta, 2015) study the sample consisted of non-swimmers.

The intervention programs varied four weeks (4 studies), to a maximum of 34 weeks (Morais, Silva, Garrido, Marinho & Barbosa, 2018). The most common duration of the experimental program was between 6 and 12 weeks (11 studies). When it comes to methods, that is, the type of training that was applied, the most common was traditional strength training with external load or body weight (10 studies). The frequency of sessions per week was between 2 and 4, and from 30 to 60 min per session.

Strength training performed on exercise machines or ergometers was used in 3 analyzed studies, while explosive strength training was used in 2 analyzed studies. When it comes to the frequency of strength training that was applied, in most cases dry strength training was applied 3 times a week (10 studies). The lowest frequency was 1 time per week (Lopes, Neiva, Gonçalves, Nunes & Marinho, 2021), while the highest frequency was 4 times per week (Pesic, et al. 2016). In addition to the mentioned, in 4 studies, the frequency was 2 times a week. When it comes to the duration of strength training and the intensity of its implementation, they are significantly different from study to study and depend on the type of training that was applied in that study. The duration of strength training on dry land in the analyzed studies ranges from 30 to 75 min, while the values of the intensity applied in them range from 60 to a maximum of 100%.

When it comes to the tested parameters, about 120 different tests were used in the analyzed studies in order to determine the effect of additional strength training on dry land on swimming performance. Some of the tests that were most used and appeared in different studies were: 50 m (8 studies), stroke length (6 studies), 100 m (5 studies), stroke rate (5 studies), swimming speed (4 surveys), result at 25 m (3 surveys).

In 4 studies, in addition to the progress of the experimental groups, a statistically significant progress of the control groups that only performed swimming training was recorded. In a study by Lopes, et al. (2021) the control group recorded a statistically significant improvement in maximum chest thrust (p=0.049). Pesic, et al. (2016) stated in their study that the control group of subjects aged 10 to 12 years recorded a statistically significant improvement in stroke length in the breast technique (sig=0.024).

Table 1 Summary of the studies concerning the influence of strength and conditioning programs on swimming performance

References	Sample Characteristics	Dry-land strength and conditioning Intervention	Swimming and dryland performance assessment	Findings in experimental group
Lopes, T. J., Neiva, H. P., Gonçalves, C. A., Nunes, C., & Marinho, D. A. (2021). The effects of dry-land strength training on competitive sprinter swimmers.	National level (n=20, 20.55 years; 14 male and 6 female) - 2 groups: • experimental (n = 11), • control (n = 9).	- Dry strength training with external loading. - 8 weeks (one training session per week). - 5 to 7 exercises, in 3 to 5 series with 6 to 12 repetitions. - Training duration 60 min. - Intensity from 60% to 80%.	Result in 50m crawl technique, result in 100m crawl technique, stroke frequency, stroke length, stroke index, anaerobic critical acceleration, maximum chest thrust, maximum squat thrust, vertical jump height, distance of thrown medicine-zinc (3kg) from sitting position.	Progress of the experimental group: result at the last 50m (p < 0.001), result at 100m (p < 0.001), stroke frequency at the last 50m (p=0.002), stroke index at the last 50m (p=0.002), stroke index at 100m (p=0.001), score at the initial 25m (p=0.001), score at 50m (p=0.001), stroke frequency at 50m (p < 0.001), anaerobic critical acceleration (p=0.010), maximum chest thrust (p < 0.001). - Progress of the control group: Maximum chest thrust (p=0.049).

Yapıcı-Öksüzoğlu, A. (2020). The effects of theraband training on respiratory parameters, upper extremity muscle strength and swimming performance.	National level (n=12 male, 16 ± 1.41 years) 2 groups: • experimental (n = 6), • control (n = 6).	Dry strength training with "TheraBand" exercise bands. - 6 weeks, 3 times a week. - 10 exercises performed in 3 series. During the first 2 series, 20 repetitions of the exercises were performed, while in the 3rd series, worked until failure. If the subjects managed to do more than 30 repetitions in the 3rd set, their load level would be increased. - Rest time: • 1 min. between series, • 2 min. between different exercises.	- Anaerobic performance: "Wingate test" on an ergometer with assessment of different power levels and fatigue index. - Maximum torque: maximum torque during flexion in the shoulder joint, maximum torque during extension in the shoulder joint. - Result in swimming: result in 100m, result in 50m. - Respiratory parameters: forced vital capacity (FVC), forced expiratory volume per second (FEV1), ratio of FEV1 to FVC, maximum ventilation capacity (MVV).	- Progress of the experimental group: maximum torque during flexion in the shoulder joint (r < 0.05), maximum torque during extension in the shoulder joint (r < 0.05). - Statistically significant differences between the groups at the final test: maximum torque during flexion in the shoulder joint (r < 0.05), maximum torque during extension in the shoulder joint (r < 0.05).
Jones, J. V., Pyne, D. B., Haff, G. G., & Newton, R. U. (2018). Comparison of ballistic and strength training on swimming turn and dry-land leg extensor characteristics in elite swimmers.	National level - 12 respondents, 10 male and 2 female, 19.4 ± 1.0 years. - 2 groups: • group applying strength training with load (n = 6), • the group applying the training ballistic/explosive forces (n = 6).	- Strength training with external load and ballistic/explosive strength training. - 6 weeks, 3 times a week. - Strength training with external load: • 6 exercises performed in 4-5 series with 5-8 repetitions, • intensity 85% - 90%, • rest time 3-4 min. - Explosive strength training: • 5 exercises performed in 4-5 series with 3-5 repetitions, • intensity 80%-100%, • rest time 2-3 min	- Characteristics of the swimming turn: impulse, turn time, time at 5m, maximum power per kilogram of mass. - Squat jump power parameters: relative squat power, maximum power per kilogram, maximum power per kilogram with additional load, impulse, impulse with additional load, maximum force, maximum force with additional load, maximum power, maximum power with additional load, maximum acceleration, maximum acceleration with additional load, mass.	- Ballistic/explosive strength training progression: maximum power per kilogram of mass, impulse with additional load, maximum force, maximum force with additional load. - Differences between groups: maximum power, maximum acceleration
Morais, J. E., Silva, A. J., Garrido, N. D., Marinho, D. A., & Barbosa, T. M. (2018). The transfer of strength and power into the stroke biomechanics of young swimmers over a 34-week period.	National level (n=27, 13.3 ± 0.85 years) 1 group: • experimental	- Traditional strength training. - 34 weeks, 3 times a week. - During the first 20 weeks: • 6 exercises, in 2 sets of 20 seconds each. - During the last 14 weeks: • 8 exercises, in 2 sets of 30 seconds each.	- Arm span, throwing speed of a 1kg medicine ball, stroke length, stroke frequency, swimming speed, result in 100m. - Testing performed in 3 moments, at the end of each macro cycle (December, March and July).	Progress: arm span (r < 0.001), backstroke speed (r < 0.001), stroke frequency (r < 0.05), swimming speed (r < 0.001), 100m result (r < 0.001). - Correlation of the speed of throwing the medicine ball with the biomechanical parameters of the stroke: • stroke length (β=0.77), • stroke frequency (β = -0.47).

Amaro, N. M., Marinho, D. A., Marques, M. C., Batalha, N. P., & Morouço, P. G. (2017). Effects of dry-land strength and conditioning programs in age group swimmers	National level (n=21 male, 12.7 + 0.8 years) 2 groups: • experimental 1 (n = 7), • experimental 2 (n = 7), • control (n = 7).	- Traditional strength training and explosive strength training. - 2 times a week for 30 min. - 5 different exercises done in 3 series with a progressive increase in the number of repetitions and duration of breaks. - 10 weeks divided into 2 periods: 1st implementation period (6 weeks), 2nd adaptation period (4 weeks).	- The mean value of the force exerted during swimming, the mean value of the mechanical impulse, the height of the vertical jump performed via the "countermovement jump", the distance of the thrown medical ball (1kg) from a sitting position and the result of the 50m crawl technique. -The testing was done in 3 different moments: 1. before the start of the experiment mental program, 2. after the end of the implementation period, 3. after the end of the adaptation period.	- Progress of traditional strength training: height of vertical jump measured by "countermove-ment jump" (r < 0.01) after implementation period. - Progression of explosive strength training: height of vertical jump performed via "countermovement jump" (r < 0.05) after the implementation period, distance of thrown medical ball from a sitting position (r < 0.01) after the period implementation, result in 50m crawl technique (r < 0.01) after the adaptation period.
Rejman, M., Bilewski, M., Szczepan, S., Klarowicz, A., Rudnik, D., & Maćkała, K. (2017). Assessing the impact of a targeted plyometric training on changes in selected kinematic parameters of the swimming start.	National level (n=9 male, 21.89 ± 3.41 years) 1 group: • experimental	- Plyometric training. - 6 weeks, 2 times a week for 75 minutes per training session. - 9 exercises that were performed in 2 to 5 series, with 10 repetitions of the exercises per series	- Start time, take-off time, flight time, glide time, take-off angle, entry angle, slip angle, slip depth, take-off speed, average flight speed, average glide speed, current take-off speed, entry current speed, current glide speed, diff. ka between the current takeoff speed and the current entry speed, the difference between the current entry speed and the current glide speed.	Progression: Start Time (r < 0.01), Glide Time (r < 0.01), Average Takeoff Speed (r < 0.05), Average Flight Speed (r < 0.01), Average Speed glide speed (r < 0.01), instantaneous take-off speed (r < 0.01), input instantaneous speed (r < 0.01), instantaneous glide speed (r < 0.01), glide angle (r < 0.01). - Correlation of start time and the following parameters: gliding time (r = -0.93), average gliding speed (r = -0.67), current gliding speed (r = –0.78), average take-off speed, but only after applying the plyometric program (at the beginning r = -0.28; after completion r = -0.72).

Grant & Kavaliauskas (2017). Land based resistance training and youth swimming performance.	National level - 9 respondents, 4 male and 5 female, average 13 years. - 1 group: • experimental	- Strength training with external load. - 7 weeks, 2 times a week for 1 hour. - 7 exercises performed in 3 series with 8 to 15 repetitions. - 1 to 3 min. breaks between sets.	- Anthropometric characteristics: body height, body weight, fat percentage, amount of adipose tissue, amount of lean mass, amount of muscle tissue, BMI. - Physiological parameters, strength parameters and performance parameters in swimming: flexibility (“Sit-and-Reach Test”), vertical jump height via “sountermovement jump”, left hand grip strength, right hand grip strength, strength back and legs, repetitive strength of upper limbs (number of push-ups in 60 sec.), repetitive strength of abdominal muscles (number of sit-ups in 60 sec.), V̇O-2peak, result at 5.5 m, result at 100 m crawl, result in the selected discipline.	Progress: height of vertical jump via “sounte-rmovement jump” ($p < 0.05$), back and leg strength ($p < 0.05$), number of push-ups in 60sec. ($p < 0.05$), body height ($r < 0.05$) Statistical analysis was not performed for swimming performance in the selected discipline, due to the diversity of disciplines chosen by the participants. The authors reported progress in 6 out of 9 subjects, and the average progress in the chosen discipline is 1.21%. Deterioration: score at 5.5 m ($r < 0.05$), amount of lean mass in men ($p < 0.05$), amount of muscle tissue in men ($p < 0.05$).
Naczk, M., Lopacinski, A., Brzenczek-Owczarzak, W., Arlet, J., Naczk, A., & Adach, Z. (2017). Influence of short-term inertial training on swimming performance in young swimmers.	- 14 respondents, both sexes, average age 15.8 ± 0.4 years. - 2 groups: • experimental (n = 7), • control (n = 7). - Experienced swimmers with competitive experience.	- Inertia training. - 4 weeks, 3 times a week. - 4 series lasting 15 sec., with 2 min. rest between sets. - Maximum intensity of work with a flywheel weighing 19.4 kg. - The work was focused on the muscle groups engaged in the water stroke phase of the crawl and dolphin techniques.	- Maximum force exerted on an inertial device, maximum power measured on an inertial device, electrical activity m. triceps brachii, result in 50m crawl technique, result in 100m dolphin technique, muscle mass.	- Progress of the experimental group: maximum force by 12.8% ($r < 0.01$), maximum power by 12.8% ($r < 0.01$), result at 100m -1.83% ($r < 0.01$), result at 50m by -0.76% ($r < 0.01$), electrical activity m. triceps brachii by 22.7% ($r < 0.01$). - Statistically significant correlations: • maximum force and result at 100m ($r = -0.85$) • maximum power and result in 100m ($r = -0.83$) • maximum force and result at 50m ($r = -0.86$) • maximum power and result at 50m ($r = -0.80$)

Pesic, M., Okičić, T., Madić, D., Dopsaj, M., Djurovic, M., & Djordjevic, S. (2016). The effects of additional strength training on specific motor abilities in young swimmers.	- 60 subjects of both sexes, aged 10-14 years. - 4 groups: • experimental 1, • experimental 2, • control 1, • control 2. - Experienced swimmers.	- Training with external load. -12 weeks, 4 times a week for 45 minutes per training session. - 4 series with 10 to 15 repetitions. - 3 mesocycles: 1st mesocycle - work time 20 sec., rest time 40 sec. 2nd mesocycle - work time 30 sec., rest time 30 sec. 3rd mesocycle - work time 40 sec., rest time 20 sec.	- Start time in 10m crawl technique, start time in 10m breaststroke technique, result in 10m crawl technique, result in 10m breaststroke technique, turn time on 5+5m crawl technique, time turns at 5+5m breaststroke technique, stroke length in crawl technique, length of stroke in breast technique, efficiency of stroke in crawl technique, efficiency of stroke in breast technique, number of strokes in crawl technique, number of strokes in breast technique, length of start in crawl technique, length of start in breast technique, length of turn in crawl technique and length of turns in breast technique.	- Results of subjects aged 10-12 years: 1. progress of the experimental group: start time in 10m breaststroke (sig=0.001), result in 10m breaststroke (sig=0.028), length of turn in breast technique (sig=0.039). 2. progress of the control group: stroke length in breast technique (sig=0.024). - Results of respondents aged 13-14 years: 1. progress of the experimental group: stroke efficiency in the crawl technique (sig= 0.001).
Junior, E. B., Aidar, F. J., de Souza, R. F., de Matos, D. G., Camara, M. B., Gomes, A. A. B., ... & Garrido, N. D. (2016). Swimming performance evaluation in athletes submitted to different types of strength training.	- 24 male respondents, aged 15 to 16 years. - 3 groups: • the group that practiced strength training in water with additional resistance using a belt, • the group that practiced strength training on dry land with external load, • control. - Experienced swimmers with competitive experience.	-Strength training on dry land with external load and strength training in water with additional resistance using a belt. - 8 weeks, 2 times a week. - Training leads with a belt: • 3 series with 2 series each lasting 30 seconds. and 10 sec. breaks • 2 min. of rest between main series - Strength training on dry land with external load: • 3 series with 10 repetitions of exercises • intensity from 60% to 80%.	- Result at 25m and result at 50m - Testing performed in 3 moments: 1. before the start of the experimental program, 2. 4 weeks after the start of the experimental program, 1. 3. at the end of the experimental program.	Progress: 25m score in both types of strength training at the end of the experimental program

Sadowski, J., Mastalerz, A., Gromisz, W., Jówko, E., & Buszta, M. (2015). The effects of swimming and dry-land resistance training programme on non-swimmers.	- 30 male respondents. The average age of the respondents was 20.8 + 0.9 years. - 2 groups: • experimental (n = 17), • control (n = 13). - swimmers without competitive experience.	- Training on hydroisokinetic ergometer. -12 weeks, 3 times a week. - 6 series per training session, and each series consisted of 50 seconds. work and 10 sec. vacation. - The intensity was increased when the number of strokes per minute exceeded 60.	- Isometric strength (“IS” test), endurance in isometric strength (“ISE” test), result at 25m crawl technique, with hands only starting from the water pushing against the wall, result at 75m crawling technique, only with hands starting from the water pushing off the wall wall, stroke length, stroke frequency, force on the 10-second swim (“TS10”), the force exerted by the 30-second swim (“TS30”).	- Progress of the experimental group: “IS” test by 6.91% ($p < 0.05$), “ISE” test by 32.03% ($p < 0.001$), result at 25m by 9.55% ($p < 0.001$), result at 75m by 9.26% ($p < 0.001$), stroke length by 9.66%, ($p < 0.05$), “TS10” test by 16.71% ($p < 0.001$), “TS30” test by 14.66% ($p < 0.001$). - Progress of the control group: result at 25m by 7.95% ($p < 0.05$), result at 75m by 7.96%, ($p < 0.05$), “TS10” test by 9.31%, ($p < 0.05$), “TS30” test for 9.30%, ($p < 0.05$).
Dingley, A. A., Pyne, D. B., Youngson, J., & Burkett, B. (2015). Effectiveness of a dry-land resistance training program on strength, power, and swimming performance in paralympic swimmers. Effectiveness of a dry-land resistance training program on strength, power, and swimming performance in paralympic swimmers.	- 7 respondents, 1 male and 6 female, average age 19.4 years. - Only 1 group. - Experienced swimmers with competitive experience	- Traditional strength training. - 6 weeks, 3 times a week for 1 hour. - 3 series with a maximum of 8 repetitions each, except for the exercises of the abdominal muscles, which were done with 20 repetitions or 55 seconds. -2 min. rest between sets. - The intensity varied from 85% to 102%.	acceleration when starting from the starting block, mean value of explosive power per kilogram, highest value of explosive power per kilogram, rebound speed from the starting block, result at 5m, result at 15m.	• the speed of performing a squat jump ($r = 0.78 \pm 0.37$), • countermovement jump execution speed ($r = 0.56 \pm 0.54$). - Correlation of swimming speed values with the thickness of skin folds ($r = 0.50, \pm 0.57$).

Weston, M., Hibbs, A. E., Thompson, K. G., & Spears, I. R. (2015). Isolated core training improves sprint performance in national-level junior swimmers.	- 20 respondents, both sexes. The average age of the subjects was 16 ± 1 years. - 2 groups: • experimental (n=10), • control (n=10). - Experienced swimmers with competitive experience.	- Isolated core strength training. - 12 weeks, 3 times a week. - 7 exercises in 2 series. - The duration of the series was 60 sec., as well as the rest between them.	- Result at 50m, pulling with straight arms on the lat machine, hold on the forearms, electromyographic activity m. obliquus externus abdominis during maximal voluntary contraction, electromyographic activity of superficial lumbar multifidus during maximal voluntary contraction, electromyographic activity of m. latissimus dorsi during maximal voluntary contraction.	Progress of the experimental group: result at 50m (1.4%). Progress of the experimental group compared to the control group: • result at 50m (-2 sec.), • pulling with straight arms on the lat machine (+23.1 kg), • hold on your forearms (9 sec.), • electromyographic activity of m. obliquus externus abdominis (+7.7mV), • electromyographic activity of the superficial lumbar multifidus (+16.2mV), • electromyographic activity m. latissimus dorsi (+5.9mV).
Popovici, C., & Suciu, M. A. (2013). Dry land training and swi-mming performa-nce in children aged 11-12 years.	- 20 respondents, female, aged 11 - 12 years. - 2 groups: • experimental (n=10), • control (n=10). - Experienced swimmers	- Training using a biometric isokinetic trainer. - 4 weeks, 3 times a week. - 5 series lasting 35 seconds per series.	- Result in 50m fly stroke, swimming speed in 50m fly stroke.	- Progress of the experimental group: result at 50m ($p < 0.001$), swimming speed at 50m ($p < 0.001$). - Progress of the control group: score at 50m ($p < 0.05$), swimming speed at 50m ($p < 0.05$). - Difference between groups in results: 1. at the beginning ($p < 0.05$), 2. at the end ($p < 0.01$).
Sadowski, J., Mastalerz, A., Gromisz, W., & NiŸnikowski, T. (2012). Effectiveness of the power dry-land training programmes in youth swimmers	- 26 male respondents, average age 14 years. 2 groups: • experimental (n=14), • control (n=12). - Experienced swimmers	- Training on hydroiso-kinetic ergometer. - 6 weeks, 3 times a week. - 6 series lasting 50 sec. with 10 sec. rest between sets. - The intensity is adjusted in relation to the number of back-rows performed by the subject per minute. If this number exceeds 60, the intensity is increased.	- Isometric strength, result at 25m, stroke length, stroke frequency, force production during swimming.	- Progress of the experimental group: force production during swimming by 9.64%, ($p<0.02$).

Girold, S., Jalab, C., Bernard, O., Carette, P., Kemoun, G., & Dugué, B. (2012). Dry-land strength training vs. electrical stimulation in sprint swimming performance.	- 24 respondents, 12 men and 12 women, average age 21.8 years. - 3 groups: • a group that practiced traditional strength training on dry land (n = 8), • the group that practiced strength training using the electrostimulation method (n = 8), • control (n = 8). - Experienced swimmers.	- Traditional dry strength training and strength training using the electrostimulation method. - 4 weeks. - Traditional strength training: • 3 times a week, • 3 exercises, in 3 series with up to 6 repetitions, • 2 min. rest in between series. - Electro stimulation method: • 3 times a week, • 15 min. per session.	- Swimming speed, stroke length, stroke frequency, - Testing was done in 3 moments: 1. at the beginning of the program 2. at the end of the program 3. 4 weeks after the end of the program	- Progress of traditional strength training: swimming speed (r<0.05), stroke length (r<0.05), - Progress with the electro stimulation method: swimming speed (r<0.05), - The recorded progress of the parameter in both groups existed even after 4 weeks from the end of the program. - Correlation of swimming results with the following parameters: • stroke length (r = 0.96; p < 0.05) in traditional strength training. • maximum hand extensor torque by eccentric contraction at an angular velocity of -60°.s-1 (r = 0.99; p < 0.05) in the electrostimulation method.

DISCUSSION

The analysis of the studies included in this research shows that additional strength training on dry land has a positive effect on the swimming performance of adult swimmers (over 19 years old). In all studies in which the sample of respondents was older than 19 years, statistically significant improvements in the tested parameters were recorded. Please note that the respondents in all studies examining the impact of additional training on dry land in adults were in early adulthood (up to 25 years old).

As is well known, differences in strength and anthropometric characteristics exist between the sexes (Seifert, Barbosa & Kjendlie, 2010; Seifert, Boulesteix & Chollet, 2004; Seifert & Chollet, 2008). These differences are small in the prepubescent period (Faigenbaum, Lloyd, MacDonald, & Myer, 2016), but after puberty they become more pronounced and men exhibit higher levels of strength than women (Bencke, Damsgaard, Saekmose, Jørgensen, Jørgensen, et al. 2002; Bergeron , Mountjoy, Armstrong, Chia, Côté, et al. 2015).

Despite this, in 9 of the analyzed studies, the sample of respondents consisted of members of both sexes. The results of these studies should be analyzed with particular care because of a possible gender effect. Unfortunately, of these 9, only in the studies of Grant & Kavaliauskas (2017) and Girold, et al. (2012) the effect of gender was taken into account. In the study by Grant & Kavaliauskas (2017), the differences in the gender of the subjects were shown to be significant only in terms of anthropometric characteristics, while in the study by Girold, et al. (2012) reported no differences in training effects between men and women. Due to all of the above, based on these 9 studies, we cannot gain a clear insight into the effect of additional strength training on dry land on swimming performance in relation to gender. Nevertheless, considering that in all 9 studies a statistically significant improvement of some of the tested parameters was reported as a consequence of additional strength training on dry land, we can draw a general conclusion that additional strength training on dry land led to positive effects in studies in which the sample respondents consisted of both sexes.

When it comes to studies with only a male sample of respondents, there were 6 of them, and in each of them, statistical significance of the progress of some of the tested parameters as a result of additional strength training on dry land was recorded.

The only female sample of respondents was in the study by Popovici & Suciu (2013) in which, as a result of additional strength training on dry land, a statistically significant improvement in the 50 m result ($p < 0.001$) and 50 m swimming speed was reported ($p < 0.001$). Also, the difference between the control and experimental groups increased from statistically significant ($p < 0.05$) at the beginning of the test to statistically very significant ($p < 0.01$) at the final test. All these results indicate that additional strength training on dry land has positive effects in members of both sexes.

As mentioned earlier, traditional strength training with external load in the form of weights or body weight exercises was the most frequently applied training method in the analyzed studies. Out of 10 studies in which this method was applied, even in 7 it gave positive effects on swimming performance or one of the parameters of the technique. Studies in which there was no statistically significant improvement in swimming performance are Jones, Pyne, Haff & Newton (2018), Grant & Kavaliauskas (2017) and Amaro, et al. (2017). A study by Jones, et al. (2018) compared the impact of this type of training with explosive strength training on swimming turn characteristics and leg extension movement characteristics in elite swimmers. Unfortunately, traditional strength training did not provide statistically significant positive effects on any of the tested parameters. The authors believe that the lack of effects is caused by insufficient duration of the experimental program for this level of swimmers, insufficient recovery time between training sessions and low strength levels at the beginning of the experimental program (especially in the group that performed traditional strength training.). In the study by Grant & Kavaliauskas (2017), swimming performance was tested for 100 m crawl technique as well as swimming of the discipline of choice. A statistically significant improvement in the performance of the 100 m crawl technique was not recorded, but an improvement in performance in the discipline of choice was recorded in 6 out of 9 subjects, which was an average of 1.21%. Please note that due to the diversity of the selected disciplines, statistical analysis of the obtained data for the performance of this tested parameter was not performed. There was also a statistically significant improvement in power parameters, as well as a statistically significant deterioration in time at 5.5 m ($r < 0.05$). We have already discussed the possible causes for this deterioration in performance in the chapter on the dependence of the effect of additional strength training on dry land on the age of the subjects, and for that reason we will not repeat it here.

In the study by Popovici & Suciu (2013), additional dry strength training was performed on a biometric isokinetic trainer. The experimental group, in which it was applied, improved statistically very significantly in the result at 50 m ($p < 0.001$) and swimming speed at 50 m ($p < 0.001$). These were also the only 2 parameters tested in this study. The control group also achieved a statistically significant improvement in both tested parameters (score at 50 m ($p < 0.05$), swimming speed at 50 m ($p < 0.05$)), but it was smaller than the progress of the experimental group.

The electrostimulation method was used in the study by Girold, et al. (2012). As an effect of its use, a statistically significant increase in swimming speed by +1.7 ± 0.5% ($p < 0.05$) was recorded, as well as a statistically significant increase in several parameters of muscle strength. The testing of subjects in this study was done 4 weeks after the end of the experimental program, and all the achieved effects were still present.

The start from the starting block and turns in swimming are actions that are most often associated with the strength of the swimmer, and as such with strength training (Beretić, Đurović, Okičić, & Dopsaj, 2013). The execution of these actions is done with explosive movements, so the development of explosiveness is mainly the goal of all training programs used for the purpose of their improvement. In order to achieve this goal, coaches and experts most often choose to apply some form of explosive strength training, of which polymetric training stands out as a very common choice.

Of all the research that this study included, in 14 of them the sample of respondents consisted of experienced swimmers with competitive experience. In the remaining 2 studies, the sample of respondents in one consisted of non-swimmers (Sadowski, et al., 2015), while in the other it consisted of recreational swimmers (Yapıcı-Öksüzoğlu, 2020).

A positive effect of additional strength training on swimming performance in experienced swimmers was noted in all studies except the study by Jones, et al. (2018) and Sadowski, et al. (2012). The reasons for the absence of larger and significant effects of the experimental programs that were applied in these studies are stated in the previous chapters and are not related to the level of experience of the swimmers.

Significant effects of additional strength training on dry land on swimming performance were also absent in recreational swimmers in the study by Yapıcı-Öksüzoğlu (2020). After application of dry-land strength training using "TheraBand" exercise tires for 6 weeks, the only statistically significant improvement was noted in maximal shoulder flexion torque ($r < 0.05$) and maximal shoulder extension torque ($r < 0.05$). There was no significant improvement in swimming performance, but a tendency of their development was observed. The authors of this study did not provide possible reasons for the lack of larger and significant training effects.

CONCLUSION

Based on the carefully analyzed results of the studies included in this research, it can be concluded that additional strength training on dry land has a positive effect on swimming performance. This research has shown that different types of strength training, if properly planned and implemented, have positive effects on the swimmers who apply them. The results of the analyzed studies show that by applying additional strength training on dry land, an improvement in the time to 50 to 5.32% can be expected. When it comes to the result at 100 m, that progress can be up to 4.34%, while the swimming speed itself can be improved up to 3.6%.

For the development and improvement of the swimming start, plyometric training proved to be a safe option in this study as well. When it comes to the age of the subjects, it was shown that additional strength training on dry land has a positive effect on adults and adolescents, with a note that the application of hydroisokinetic ergometer training is not recommended for younger swimmers. There were no subjects of prepubertal age in any of the analyzed studies.

The results of the analyzed studies show a positive impact of additional strength training on dry land regardless of the gender of the subjects, but a larger number of studies should also take into account the effect of gender when forming groups and analyzing data. When it comes to the swimmer's experience, additional strength training on dry land has a positive effect on the development of swimming performance in all levels of swimmers. As expected, the results showed that the effects are greater in lower level swimmers because they need less training stimulus to initiate positive changes.

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