

Effects of Strength training on Sprint Swim performance

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Translation: Mariëlle Thorissen ~~dit toevoegen in de acknowledgements; hoort hier niet thuis~~

Summary

Several forms of strength training were compared to determine which strength training programme had the most positive effect on sprint swim performances. The study population consisted of three head groups: an endurance group (D) acting as a control group (N = 28), a sprint group (S) (N = 39) and a dry-land strength training group (L) (N = 29). Baseline measurements were recorded at the start of the swim season after all subjects had trained five times a week during two weeks at the same relative intensity. During the thirteen weeks intervention period they trained five times a week. Three training programmes were identical for all groups and two training programmes were group-specific. The two specific training sessions per week consisted of: endurance training for group D, sprint training for group S and dry-land strength training for group L. The sprint group (S) was divided in three sub-groups. Group Sa trained without equipment, group Sb trained using drag suits, and group Sc with hand paddles. Within the sprint group (Sa, Sb, Sc) the same training programmes were used. During the dry-land strength training they used apparatus and dumbbells at a front-crawl sprint specific frequency. The dry-land strength-training form did not lead to significant improvement in swim performance, this in contrast with a specific swim programme for sprint swimmers.

Introduction

The purpose of swim training is to systematically bring about specific adaptations to improve performance capacity of swimmers. Several performance determining factors are influenced during swim training. One of these factors is strength. The fact that a positive correlation has been discovered between power (is strength x velocity) of swimmers and their swim performances (10, 12, 13, 17, 19) makes swim instructors trying to accomplish power improvement through strength training. They assume that strength training leads to larger performance capacity and therefore to improvement in swim performances. Strength training is carried out both in water and on dry land. It is uncertain whether dry-land strength training leads to improved sprint performance capacity during swimming. When there is a bad transfer between the effects of dry-land strength training to swim performance, this could be explained by the fact that dry-land strength training is not 'specific' enough (2,4,6,15, 20). Different factors determine to what extent training progress in one situation leads to improved performance in the other. With strength training previous studies showed that training effects are angle and velocity-specific. This suggests that effects of dry-land strength training are transferred to the swimming situation if during strength training people move just as fast or even faster than during swimming in water (2, 20). Moreover, it is important that not only the movement velocity during strength training corresponds to that during swimming, but also that the joint angle where (peak) strength is produced is equal. This is difficult to realise because the hand velocity fluctuates during the performance of the different swimming strokes. Besides, complex movement patterns are performed then. These movement patterns are difficult to imitate on dry land (15). This all suggests that during dry-land training, the strain on the various muscle groups strongly differs from that while swimming in water (16), so it is not obvious that dry-land strength training contributes to improved swim performances. Manufacturers of different commercially available exercise machines claim

that these machines enable swim specific training on dry-land (minigym isokinétique, élastique, callkraft exergénie). Unfortunately, there is little scientific proof for this assertion. The movement patterns made with these equipment items during training differ strongly from the movement patterns in water (6, 7, 15). According to this, it is no surprise that there is no literature that proves the effectiveness of these exercise machines. During training with a power-rack where a weight has to be pulled) or swimming with hand paddles, the movement pattern resembles much more the movement pattern that is made during 'free' swimming. Interviews with Dutch top swimmers prove that many different forms of dry-land strength training is used in swimming, despite the fact that there is no scientific proof of the effectiveness of dry-land strength training. So it lacks sufficient evidence for this practice interpretation (evidence based practice, 1, 3). The experienced swim coach has apparently 'experiential knowledge' that dry-land strength training is an effective part of the total training programme. This research study tries to contribute to evidence based practice in swimming training. Several forms of strength training are compared to find an answer to the following questions:

1. Does strength training provide a positive contribution to the 50m front crawl performance?
2. Which of the chosen forms of strength training contributes most to performance improvement on the 50m front crawl?

In view of the literature that underlines the importance of specificity of strength training, special attention was given to the similarity in frequency and velocity of movement of the dry land exercises to that of sprint front-crawl swimming (2, 4, 6, 20).

Equipment and methods

Research design

A pre-measurement and post-measurement design with randomised groups was used with an initial familiarisation phase of two weeks for all subjects, including five times week training with the same endurance programmes. During the thirteen-week lasting intervention period all subjects trained five times a week: three times a week with identical training programmes, and twice a week with group specific programmes (Table 1). The training sessions existed mainly of endurance training.

Table 1: in the following table the weekly training incentives per group are mentioned:

Name	Training form	Training 1	Training 2 (specific)	Training 3	Training 4 (Specific)	Training 5
Group D	Endurance	Combined	Endurance	Combined	Endurance	Combined
Group Sa	Sprint swimming	Combined	Sprint swimming	Combined	Sprint swimming	Combined

Sb	Sprint swimming with resistance swimwear	Combined	Sprint swimming	Combined	Sprint swimming	Combined
Sc	Sprint swimming with hand paddles	Combined	Sprint swimming	Combined	Sprint swimming	Combined
Group L	Dry-land strength training (KL)	Combined	KL	Combined	KL	Combined

The characteristics of the two specific training sessions (See Table 1, training 2 and 4).

1. Endurance group (control group). In this group no strength training or sprint swimming training was carried out. To prevent decrease in technique and endurance, this group did endurance training during the group-specific training sessions. During endurance training the group performed at a relatively low intensity for a longer time.
2. The sprint-swimming group. The exercise bouts existed of several sprint swimming forms where they swum at maximum intensity as often as possible. The programme was identical for all swimmers. This group was divided in three sub-groups that trained with or without equipment during sprint training:
Sa: sprint swimming without equipment
Sb: sprint swimming with drag suit
Sc: sprint swimming with hand paddles
3. Dry-land strength training: Apparatus and dumbbells were used in a for sprint swimming frequency specific way. During baseline measurement it was determined that the participants of this study swum the 50m front crawl with an average stroke frequency of 58 strokes per minute. To be certain that movement frequency during strength training would be comparable with movement frequency during the competition, a frequency of 60 strokes a minute was used.

Subjects

In co-operation with the Koninklijke Nederlandse Zwembond (KNZB) (Royal Dutch Swimming Association) all Dutch swim coaches were asked for participants to this study. There were 5 criteria for participation:

- Used to 5 swim training sessions a week of at least 1 hour per training
- Minimum age 17 years
- No experience with dry-land strength training
- Prepared to train for 15 consecutive weeks in the training programmes arranged by the research group
- Take note of the research protocol and sign a declaration form of 'informed consent'

124 subjects divided over 35 swimming teams applied. The swimmers that had applied were invited with their coaches for a meeting where the research protocol was explained orally and in writing. Then, 96 swimmers from 34 different swimming teams confirmed their participation in the research study in writing.

Grouping

The subjects were equally divided over the three head research groups. In order to restrict the number of fitness centres that were needed, we divided the group of subjects who were members of the clubs with the largest numbers of participants. One half was divided at

random in the dry-land strength training group (L); the other half was divided in one of the other two head groups. The sprint-swimming group was divided later at random in three sub-groups. An overview of the different groups with respect to sex, age, and weight is given in Table 2.

Table 2: information with regard to sex, age, and weight of the three main groups (D, S, L). Group S was divided in three sub-groups (Sa, Sb, Sc) \pm is the standard deviation.

	Group D	Group Sa	Group Sb	Group Sc	Group L
	15 male 14 female	8 male 5 female	8 male 6 female	8 male 4 female	15 male 12 female
Age	22 years ca. 8.7	19 years ca. 1.6	19 years ca. 1.9	22 years ca. 7.0	22 years ca. 8.8
Weight	70.0 kg ca. 9.1	64.8 kg ca. 10.3	64.5 kg ca. 8.2	75.3 kg ca. 13.9	67.4 kg ca. 8.7

Instruction

After signing the declaration form of informed consent, the subjects received instructions that contained, among others, the training programmes of the swim training and the dry-land strength training. The swim training programmes were formulated by one of the researchers (MSc, course leader KNZB) and further tested by a forum of selected swim coaches. The other researcher (MSc, lecturer physical education) formulated the dry-land strength training. The dry-land strength training group (L) received, besides instructions, an oral explanation of the strength training method and the required exercises. The instructors of the various fitness centres received oral instructions by one of the researchers.

Adherence to the training programme

The compliance to the required training programme (training compliance) was encouraged by:

- Keeping a training logbook by subjects
- Telephone contact on a weekly basis between subjects and research team
- Continuation report of the research study via a website
- Availability of researchers for answering questions of subjects
- Frequent e-mail contact with swim coaches and fitness instructors

Measurements

Competition analysis

During the pre-measurement and post-measurement several performance determining factors were measured:

- Race analysis of all subjects were made during an official competition
- Various measurements were carried out with the MAD-system (19)
- Anthropometrics (study of human body measurements and properties) was carried out

Stroke length, stroke frequency and 'pure' swimming speed were determined for each 25m lap with Silicon Coach Pro (See for position of the three cameras Figure1) during swimming of four different 50 m competitions (front crawl, butterfly, backstroke, breaststroke). The swimmers were timed with electronic timing. The stroke cycles during the length was expressed in a percentage of the potential stroke length (%PSL) or the measured stroke length divided by four times the measured arm length (14).

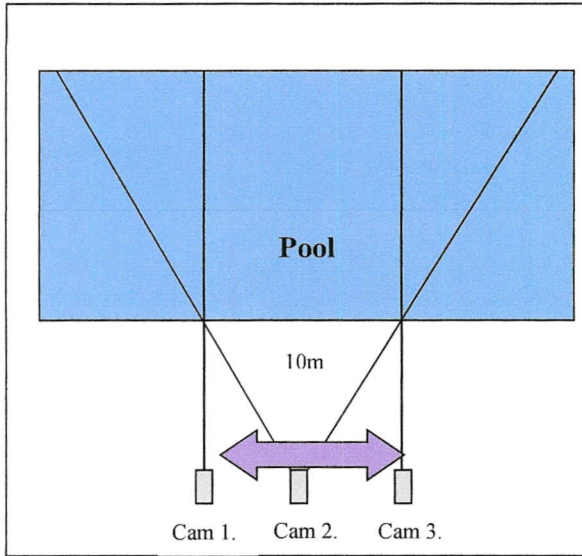


Figure 1: camera position for race analysis

MAD-measurements

Strength, velocity and power were measured with the MAD-system (Measure Active Drag) (19, 20). The system exists of a 22m long rod where every 1.35m fixed pads are attached. This rod is mounted about 0.8m below the water surface. The rod is connected to a force transducer enabling direct measurement of push-off forces during each stroke. Maximum sprints were swum on the MAD-system in two conditions: sprinting while using the whole stroke or swimming only with the arms. The measured drag force (F_d) depends on the square of velocity (v^2) according to $F_d = A \cdot v^2$ (11). A is a factor of proportionality incorporating among others the swimming technique and size of the swimmer. The pure swimming speed of sprints that were swum without the MAD-system was established by a camera set up. During the MAD-swimming the swimmer pushes off from a fixed point. During 'free' swimming the swimmer pushes off from water that starts moving. Therefore, when creating propulsion, power is transferred to the water to setting the water in motion. As a result, only one part of the power can be converted into velocity. With MAD arms-only swimming the total power is used for that. Therefore, propulsion efficiency of swimming (e_p) can be determined as the proportion between v_{free}^3 and v_{mad}^3 (22)

$$e_p = \frac{P_{dragfree}}{P_{dragMAD}} = \frac{A \cdot v_{free}^3}{A \cdot v_{mad}^3} = \frac{v_{free}^3}{v_{mad}^3}$$

A practise day was organised for the subjects before the subjects were measured on the MAD-system. This was to prevent improvement that was measured based upon a learning effect.

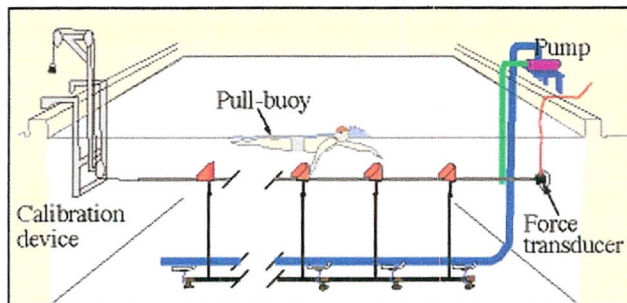


Figure 2: side and front view of the MAD-system

Statistics

The intended analysis of variance for repeated measures analysis with SPSS (Statistical Package for the Social Sciences) could not be used, because the absolute data were not normally distributed, but the relative change of the various parameters was, and so it was decided to compare these with each other (9). A one-way ANOVA was used for the data analysis of the relative improvement. In addition, a paired t-test was used to determine significance of changes between pre-measurement and post-measurement.

Results

Relative improvement in swimming time on the 50m front crawl

The swimming time of the 50m front crawl improved in group S with 2.2 %. This was significantly more than the 0.8 % improvement in group L ($p < 0.05$, Figure 3). The improvement in group S proved to be associated with a significant increase in stroke frequency in the second part of the race (Figure 5). Between group D and group S was no significant difference in improvement. Table 3 shows that the groups that trained in water booked significant improvement in contrast with the dry-land strength-group (group-L).

Relative improvement in swimming time on 50m front crawl
with regard to pre-measurement

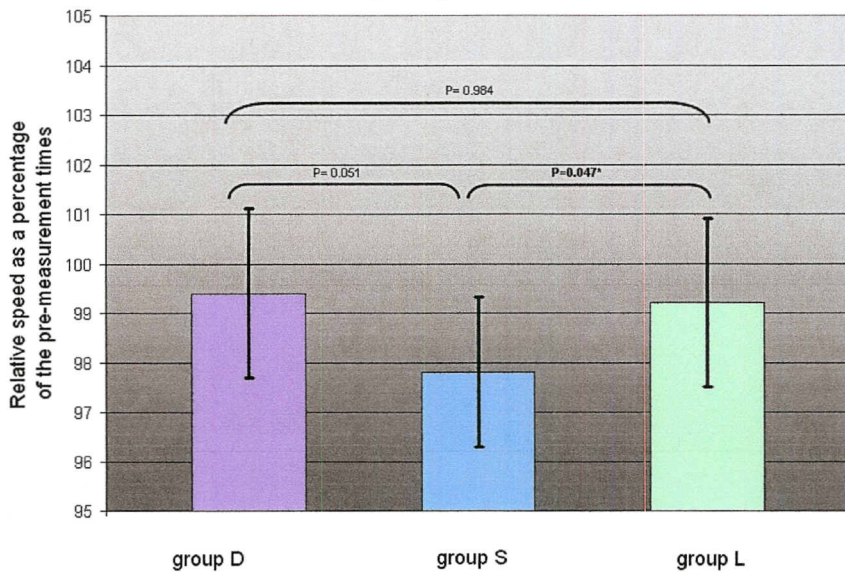


Figure 3: relative improvement in swimming time between pre-measurement and post-measurement for group D, S and L on the 50m front crawl

Table 3. Indicates the value of a t-test with regard to absolute improvement in swimming time and average finish times of the pre-measurement and post-measurement. The t-test was performed on the data of group D, S, and L. Group S was divided in 3 sub-groups: Sa, Sb, and Sc.

Group	Time improvement		P-value	Relative improvement (%)
	Pre (s)	Post (s)		
D	29.3	28.4	0.05*	0.9
S	28.5	27.9	0.00*	2.2
a	28.9	28.2	0.01*	2.6
b	28.1	27.5	0.00*	2
c	28.8	28.2	0.24	2
L	28.6	28.4	0.11	0.8

2. Relative change in stroke length

The stroke length was not influenced by the intervention (Table 6).

3. Relative change in stroke frequency

The stroke frequency on the first 25m did not change in the groups after the intervention (Figure 5). However, on the second 25m the stroke frequency increased significantly more in group S than in the other groups. According to Table 4 the average difference in stroke frequency between pre-measurement and post-measurement was 1.2 strokes a minute. This was a significant improvement ($p=0.00$). The dry-land strength-group showed a significant decrease in stroke frequency on the way back ($p=0.05$). The average decrease was 1.1 strokes a minute.

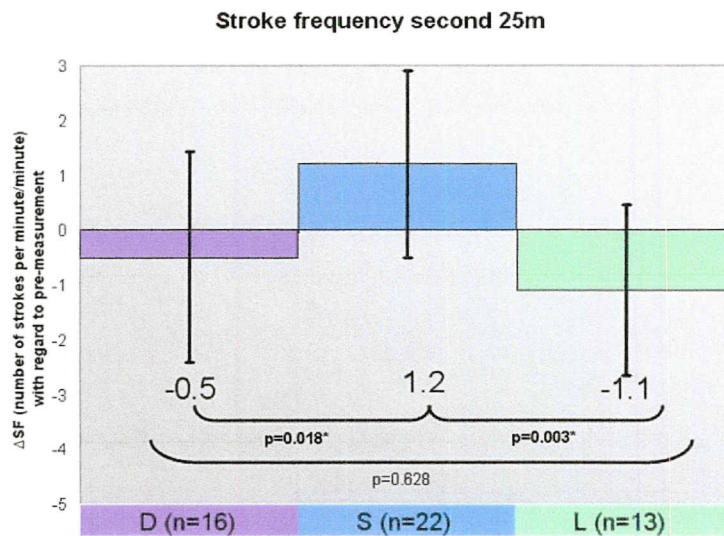
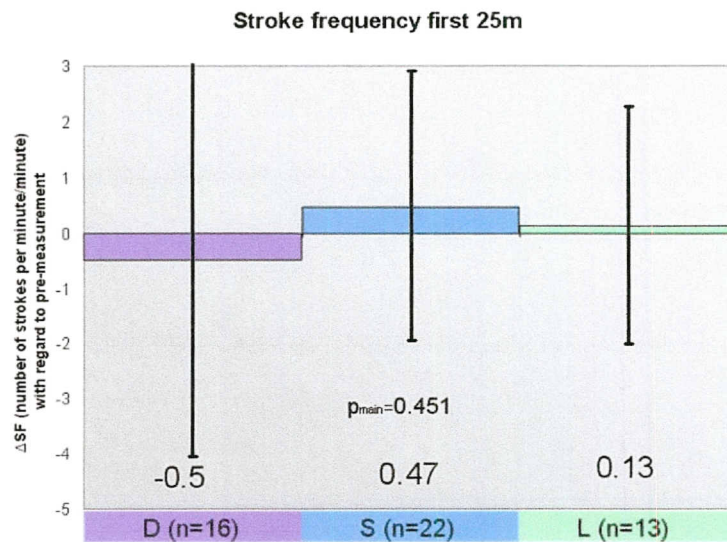


Figure 5: increase/decrease in number of strokes per minute between pre-measurement and post-measurement of the first and second 25m of the 50m front crawl

Table 4 indicates the value of the t-test and the stroke frequencies of the pre-measurement and post-measurement of the second lap of the 50m front crawl. The t-test was performed on the data of group D, S, and L. Group S was divided in 3 sub-groups: Sa, Sb, and Sc.

Group		Stroke frequency		P-value
		Pre	Post	
S		52.5	51.5	0.36
		53.4	54.9	0.00*
	a	53.3	54.6	0.18
	b	52.3	54.1	0.01*
	c	57.5	57.4	0.85
L		52.8	51.1	0.05*

MAD-measurements

Mad-measurements condition of the sprint velocity provided the same picture as the one determined during the competition: after the intervention the speed of arms-only swimming increased significantly more in group S than in group D (endurance group). With regard to the MAD-measurement, only for group Sc a significant increase in resistance factor (A) was found.

All results are given in the [Tables 5](#) and [Table 6](#).

[Table 5](#): reflects the static results of the 50m front crawl. The numbers in the angles of the triangle correspond with the groups. The p-value in the middle gives the overall p-value. The p-values on the sides of the triangle indicate the differences between the groups. The red signs ‘larger than’, ‘smaller than’, or ‘just as large’ show which group more or less improved. The factors that we compared were:

- Relative improvement in time
- Change in the percentage of the possible stroke length (%PSL)
- Change in the stroke frequency on the first lap of 50m front crawl
- Change in the stroke frequency in the second lap of the 50m front crawl

Competition analysis head groups			
Front crawl			
Time	Stroke length	Frequency first 25m	Frequency second 25m
Competition analysis sub-groups			
Front crawl			
Time	Stroke length	Frequency first 25m	Frequency second 25m

[Table 6](#): reflects the static results of the MAD-measurements. The numbers in the angles of the triangle correspond with the groups. The p-value in the middle gives the overall p-value. The p-values on the sides of the triangle indicate the differences between the groups. The red signs ‘larger than’, ‘smaller than’, or ‘just as large’, show which group more or less improved. The factors that we compared were:

- Velocity during arms-only swimming on the MAD-system
- Velocity during arms-only swimming beside the MAD-system
- Produced strength during arms-only swimming on the MAD-system
- Produced strength during arms-only swimming on the MAD-system
- E_p of arms-only swimming
- Velocity during combination swimming on the MAD-system
- Velocity during combination swimming beside the MAD-system

- E_p of combination swimming
- 'A' value during arms-only swimming
- 'A' value during combination swimming
- 'A' value during arms-only swimming, divided by 'A' value during combination swimming

MAD-measurement head groups				
Arms				
Velocity-MAD	Velocity-free	Force	Power	Propeff
Combination				
Velocity-MAD	Velocity-free	Force	Power	Propeff
MAD-measurement sub-groups				
Arms				
Velocity-MAD	Velocity-free	Force	Power	Propeff
Combination				
Velocity-MAD	Velocity-free	Force	Power	Propeff

Discussion

Improvement in swimming time

After thirteen weeks of training, the sprint group (S) and the endurance group (D) swam significant faster times on the 50m front crawl. The performance of the dry-land strength training group (L) did not improve. An explanation for this could be that despite the attempts to prescribe swim specific frequencies during the dry-land strength training exercises, the movement pattern, the movement speed and the muscle load differed too much from the movement pattern in water (2,6,15,20). Dry-land strength training is probably not 'specific' enough to bring about improvement in sprint swim performance. The difference in improvement between the sprint group and the endurance group was not exactly statistical significant ($p = 0.051$). This means that we can not exactly conclude that sprint training produces significant better sprint times than training of the endurance group. However, this result strongly suggests that sprint training is more specific when sprint performances must improve.

Dry-land strength training group

The dry-land strength training group did not show any improvement in swimming time on the 50m front crawl after thirteen weeks of training (t-test $p=0.114$). However, a significant decrease in stroke frequency during the second 25m was observed. The lack of performance improvement seems to be due to the little swim specific training load. Besides, the dry-land strength training sets were relatively short, with an average of 8 rehearsals per series. With a frequency of 60 per minute, a strength set took 8 seconds. The short length of time probably does not stimulate the endurance capacity enough to expect performance improvement in the second part of the race. On the other hand, the duration of the sprints performed by the sprint group in the pool was with 8 to 10 seconds about the same. It seems strange to ascribe the lack of effect to exercise time in the strength training group when similar exercise times in the other group does bring about enhancement of performance times.

After the summer break, the entire research group had only trained for two weeks before pre-measurement. After such a short preparation, it can be assumed that the performance level has not reached the level of the previous season. This makes the lack of improvement in swimming times in the dry-land strength-group after the intervention extra remarkable. That the dry-land strength-group achieved no significant improvement in swim performance however, does correspond with the results of previous studies evaluating the effectiveness of dry-land strength training (10,18). Despite the lack of significant results observed for the dry-land strength training group, a word of caution is in place. From the presented results, it can not be concluded that (all forms of) dry land training is useless to improve swimming performance. Rather, the data do not support the effectiveness of dry-land training when improvement of sprint swimming is at stake. It can not be ruled out that other forms of dry land training where for example the applied load is much higher would elicit the desired performance gains in the pool.

Stroke frequency

The stroke frequency in the sprint group decreased less on the last 25m of the 50m front crawl than in the other two groups. On the first 25m of the 50m front crawl there was no change measured in stroke frequency in the different groups. In the dry-land strength training group the stroke frequency decreased significantly with regard to pre-measurement. Recent research shows that stroke frequency decreases with increased fatigue (21). This suggests that the dry-land training group was the least successful in improving fatigue-resistance. This suggests that if dry-land exercise is incorporated in the training regime, special care should be given to the duration of the exercise such that 'fatigue'-resistance is enhanced.

The MAD-system was used to measure power, resistance and efficiency of swimming. Unfortunately the propelling efficiency was not measured during the second 25 meters (during fatigue). More research is necessary to determine the effect of strength training on stroke rate en propelling efficiency. No differences were found in these parameters, both between and within the three head groups. This is remarkable, because significant changes were found in comparable previous research studies (19).

Sub-groups

More than half of the paddle group stopped training as a result of shoulder injuries. These injuries could perhaps be blamed to the fact that the research population were not used to training with hand paddles. Because the sub-groups became smaller due to dropouts, possible differences between the groups could not be detected.

Conclusions

There was no improvement measured in swimming time on the 50m front crawl for the dry-land strength training group. This despite the instructions to perform the training with apparatus and dumb-bells in a frequency as swim-specific as possible. The lack in performance gain seems associated with a significant decrease in stroke frequency in the second part of the 50m race.

In contrast with the strength training group, 50 m race time was improved for the group with a sprint-swimming programme in water. The performance improvement after sprint training was associated with a slighter decrease in stroke frequency in the second part of the race. No change in stroke length was noticed after both sprint training and dry-land strength training. More than half of the hand paddle group had to stop the swim training because of shoulder injuries.

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