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EFFECTS OF A 12-WEEK VELOCITY-BASED TRAINING PROGRAM WITH LACTATE MONITORING ON 50 M FREESTYLE PERFORMANCE IN COMPETITIVE SWIMMERS

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ABSTRACT. *Introduction*: Training competitive swimmers involves the continuous development of general physical qualities and their subsequent application to specific performance. In sprint events, dry-land training plays a key role in developing strength and speed of execution. The objective monitoring of effort remains a significant challenge. *Objective*: This study aimed to determine the effects of implementing velocity-based training combined with swimming, alongside lactate level monitoring, to significantly improve performance compared to a traditional percentage-based programme. *Materials and methods*: Sixteen advanced swimmers, who were members of two university clubs, were divided into an experimental group and a control group. They followed a 12-week programme based on speed of execution and lactate analysis. Tests included the 50 m freestyle, determination of 1RM and speed of execution at 60% of 1RM. *Results*: Significant improvements were observed in the 50 m freestyle ($p = .03$; $d = 0.90$) and in the strength tests (1RM squat: $p = .018$; bench press: $p = .036$) in the experimental group. The control group showed minor changes, except for the bench press ($p < .001$). *Conclusions*: Speed training adjusted using lactate level testing improved performance and strength, demonstrating the effectiveness of objective monitoring and the customisation of tasks for athletes.

Keywords: fixed set velocity loss, resistance training, neuromuscular adaptation, metabolic adaptation, performance optimization

INTRODUCTION

One of the main problems faced by physical trainers is how to quantify and monitor athletes' training loads objectively in order to maximise performance. Several training variables have been identified in the design of physical training

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sessions, such as the type and order of exercises, intensity or load, number of repetitions and sets, and rest periods between sets (Bird et al., 2005; Kraemer and Ratamess, 2004). While most of these variables have received significant research attention, the possibility of manipulating the number of repetitions performed in each set relative to the maximum possible remains an unaddressed question in the literature (Sánchez-Medina and González-Badillo, 2011). Manipulating this variable determines the type of physiological responses and, ultimately, adaptations to strength training (Spiering et al., 2008). A reliable tool for assessing swimming-specific strength (both on land and in water) is evaluating strength-velocity exercises, which determine the relationship between weight lifted and speed (Gonjo et al., 2021).

Due to the limitations of percentage-based training (PBT), velocity-based training (VBT) has been suggested as a more effective way of prescribing training loads to improve general and specific performance (Włodarczyk et al., 2021; González-Badillo & Sánchez-Medina, 2010). VBT is superior to percentage-based training, particularly for elite athletes, as PBT has several limitations. Firstly, regular 1RM tests must be performed to prescribe the training load, which can lead to injury (Jovanovic and Flanagan, 2014; Włodarczyk et al., 2021). It is also impractical and time-consuming in large groups, and the values obtained contain a large margin of error (González-Badillo and Sánchez-Medina, 2010).

Secondly, changes in 1RM can occur after just a few training sessions and can fluctuate depending on physical condition, which can be caused by factors such as biological variability, training-related fatigue, lifestyle, sleep, stress and nutrition (González-Badillo and Sánchez-Medina, 2010; Jovanovic and Flanagan, 2014).

Velocity-based training approach is widely used by recreational athletes, but elite athletes use the aforementioned method differently (Hackett et al., 2018). This method enables daily readiness (or daily 1RM) to be estimated and allows speed decline within each set to be monitored in order to manage fatigue accumulation (González-Badillo and Sánchez-Medina, 2010; Jovanovic and Flanagan, 2014). Significant improvements in swimming performance have been achieved through low-volume, speed and strength training programmes when the selection of dry-land exercises is specific to the swimming event and muscle groups (Crowley et al., 2017; Crowley et al., 2018; Weston et al., 2015).

In VBT, two new variables are adopted for prescribing training load: the fastest initial repetition speed in sets is used to set the load instead of %1RM; and the velocity loss threshold (VLT) is used to finish the set instead of the traditional fixed number of repetitions. In a VBT approach, a working set is terminated if the mean concentric velocity (MV) of a repetition falls below a predetermined velocity loss threshold. The fixed set velocity loss (FSVL) method includes a predetermined training load and number of sets but not a prescribed number of repetitions (Banyard et al., 2018). For instance, Padulo et al. (2012) implemented a 20% velocity loss threshold and demonstrated that maintaining at least 80% of MV during training results in greater improvements in 1RM bench press compared to 1RM training alone (Padulo et al., 2012). Therefore, even if all participants perform the same number of repetitions per set with a given load during a training session, they may exert different levels of effort (Morán-Navarro et al., 2019; González-Badillo et al., 2017), since the number of repetitions remaining in each set can vary considerably between individuals. Instead of performing a fixed number of repetitions, it has been suggested that each training set should be stopped as soon as a predetermined magnitude or percentage of speed loss is reached (Morán-Navarro et al., 2019; González-Badillo et al., 2017; Rodríguez-Rosell et al., 2019).

Strong relationships have been observed between speed loss during weightlifting and metabolic measures of fatigue (Sánchez Medina & González-Badillo, 2011; Jovanovic & Flanagan, 2014). Research has shown that a high lactate concentration increases linearly during exercise as the number of repetitions performed in each set approaches the maximum (Sánchez Medina & González-Badillo, 2011; Gorostiaga et al., 2011). This leads to longer recovery times after training and a decrease in swimming-specific performance.

Due to the limited scientific evidence regarding the transfer of strength from land to water in swimmers, following the development of strength and speed on land, this study aims to analyse the assumption that integrating a speed-based strength development programme significantly improves performance in the 50 m freestyle event compared to the control group performing traditional strength training based on percentages. Training controlled by objective feedback also promotes significant neuromuscular adaptations.

MATERIAL AND METHODS

Study design

The present study was designed as a 12-week experimental intervention (divided into two phases: lactate training and power endurance training) aimed to compare the effects of two strength training methods on the performance of the 50 m freestyle (start from the water), with parallel groups. The study aimed to examine the effects of combining velocity-based training with swimming and adding lactate level monitoring to significantly improve performance compared to traditional percentage-based training (PBT).

Performance was evaluated using a series of tests conducted over the course of a week, with at least 24 hours' recovery time between sessions. The first testing session consisted of a swimming test, which was used as the main indicator of athletic performance. Maximum strength and execution speed were then assessed using the following methods: a) determining 1RM for squats; b) measuring execution speed at 60% of 1RM for squats; c) determining 1RM for bench press; d) measuring execution speed at 60% of 1RM for bench press.

Participants

Sixteen participants (five female and eleven male, aged 16.81 ± 2.28 years, with an average height of 174.44 ± 9.45 cm and an average weight of 65.81 ± 13.43 kg). All participants were advanced swimmers and members of two university clubs. Participants were selected based on their competitive experience and specific physical training to provide a clearer picture of the target population. The athletes were divided into two groups: an experimental group (n = 8) that performed a combined swimming and velocity-based strength training programme, and a control group (n = 8) that performed a combined swimming and percentage-based strength training programme. Parents or legal guardians of minors were required to give their consent for their children to participate in the study.

Procedure

The tests in this study were conducted under similar conditions for all participants at the same time in a controlled environment to minimise external factors. Participants were instructed to exert maximum effort during each test and to observe the recommended recovery period.

The main performance indicator is the 50 m freestyle test, which starts in the water. Prior to the test, all participants completed a standardised warm-up routine comprising 200 m crawl, 200 m medley and two 15 m sprints, to ensure neuromuscular activation. The test was conducted in two stages (pre- and post-test) with manual timing, and the total time was expressed in seconds. Maximum strength was determined for two fundamental exercises: squats and bench presses. This began with a progressive warm-up, after which the load increased from Olympic barbell lifts (without added weights) to 100–105% of the maximum, with a recovery period of 1–5 minutes between sets. The speed of execution was measured for the same exercises (squats and bench presses), with the concentric phase performed at maximum speed using a load equivalent to 60% of the previously determined 1RM. All participants underwent a specific warm-up and then performed two to three repetitions of the tested exercise.

The most common and accurate device used to measure speed during strength training is the linear position transducer (LPT). Typically, the LPT is connected to a display to provide real-time feedback on speed (Orange et al., 2020). Vitruve Fit is a linear position sensor device designed to transform the way athletes, coaches and health professionals measure and improve performance. Studies have shown these devices to have low measurement error and acceptable relative and absolute reliability (Hansen et al., 2011).

The Accutrend portable analyser was chosen for lactate level analysis because it is ranked among the most reliable and accurate field devices in the literature. Studies show that it correlates well with laboratory methods (Baldari et al., 2009; Stoll et al., 2018) and has low measurement variability. It also has the advantage of being highly practical and easy to use in a sports environment. Standard procedures were followed for the collection, management and analysis of blood lactate (Goodwin et al., 2007). Blood samples were collected from the earlobe before and after each experimental procedure.

Methods

The study intervention period lasted 12 weeks and involved three training sessions per week, supplemented by an additional mobility and flexibility session in some weeks. In addition to neuromuscular adaptations, metabolic components were integrated (lactacid training for the first seven weeks and power endurance training for the final five weeks), according to Signore (2021), to develop the anaerobic-lactic system, which is essential for sprint events.

There are three main functions of measuring lactate levels: a) validation, lactate levels can be used to confirm whether a session is lactacid or power endurance; b) adjustment, lactate levels can be used to adjust the speed loss threshold and breaks between sets. If the level is too low, breaks are reduced or volume is increased. If the level is high and speed decreases, volume is reduced or breaks are increased; c) prediction, very high lactate levels after a strength session may indicate reduced performance in swimming training.

Anaerobic lactate training (weeks 1–7) is a method that aims to improve tolerance to high blood lactate concentrations resulting from high-intensity exercise performed over short and medium durations. During training sessions, three to four sets of four to five exercises were performed, with each set lasting between 20 and 40 seconds and corresponding to approximately 10–15 repetitions. These were performed at 50–60% of 1RM with speed losses of ≤15% (0.75–1.3 m/s for the lower body and 0.60–0.80 m/s for the upper body). This speed loss threshold was determined following lactate testing one minute after the end of the set, when blood lactate concentrations are at their maximum. Test results showed values between 6 and 10 mmol/L (labelled 'lactate training' and correlated with speed loss), with higher concentrations recorded after lower body exercises. The breaks were short to medium in length to keep lactate levels high (1.5–3 minutes until the level drops to 5–7 mmol/L to maintain metabolic stress) and allow partial neuromuscular recovery.

During the second phase (weeks 8–12) of power endurance training, the intensity was reduced to 20–60% of 1RM. However, multiple sets (2–4) were performed with short breaks (30 seconds of work with a 15-second rest) between them, generating higher metabolic accumulations. The programme followed a wave-like pattern in terms of volume, ranging from two sets, four series and three exercises to three sets, four series and three exercises. Following metabolic testing, concentric speed was maintained at 0.75–1.3 m/s for the lower body and 0.60–0.80 m/s for the upper body, with a speed loss threshold of <10%. At this stage, lactate measurements were taken one to two minutes after completing a set and frequently showed values between 3 and 11 mmol/L. In some cases, when athletes intentionally exceeded the speed loss threshold, lactate levels rose above 11 mmol/L.

The most commonly used exercises during the intervention period were squats, bench presses, latissimus pulldowns, pullovers, medicine ball slams, deadlifts, plyometrics and plank variations.

Statistical analysis

Statistical analysis was performed using JASP v.0.19.3 software, which was chosen for its advanced functionality in reporting results according to APA format and for applying parametric and nonparametric tests. The level of statistical significance was set at $p < .05$ and normality of distribution was verified using the Shapiro–Wilk test supplemented by histogram analysis to avoid deviations from normal distribution. In all cases, the *p*-values were greater than 0.05, indicating a normal distribution and validating the application of parametric tests. Homogeneity between groups was verified using the Levene test, the results of which confirmed that the internal variability of the data was comparable between samples ($p \geq .05$). The results are presented as means ± standard deviation (M ± SD), including *t*-values, degrees of freedom (df), *p* and effect size (Cohen’s d).

RESULTS

The Shapiro–Wilk normality test confirmed the normal distribution of the data ($W = 0.91$, $p = .36$), validating the application of the paired samples t-test.

Results from the 50 m freestyle test, performed with a start from the water, revealed differences between the experimental group (EG) and the control group (CG). In the EG, the average time decreased from 29.55 ± 4.52 seconds to 29.06 ± 4.03 seconds. This difference was statistically significant (p = 0.03, t(7) = 2.54) and had a large effect size (Cohen's d = 0.90). This improvement of approximately half a second confirms the effectiveness of the training programme based on speed monitoring and load control.

By contrast, the control group showed no significant changes in the 50 m freestyle test (with a start from the water), with an insignificant decrease from 28.11 ± 0.81 s to 28.02 ± 0.86 s (p = .46, t(7) = 0.76), indicating a small effect (Cohen's d = 0.27). These results demonstrate that traditional percentage-based training does not significantly improve sprint performance.

Table 1. Performance variables (50 m freestyle)

Variable	Pre (M ± SD)	Post (M ± SD)	*p* value	Effect size (Cohen's d)
Experimental Group (EG)				
50 m freestyle (s)	29.55 ± 4.52	29.06 ± 4.03	.03	0.90
Control Group (CG)				
50 m freestyle (s)	28.11 ± 0.81	28.02 ± 0.86	.46	0.27

Note. EG = Experimental Group; CG = Control Group. Significant differences at p < .05.

The results suggest that velocity-based training, adjusted according to monitored lactate levels, contributed to improved performance. Figure 1 shows the differences in performance before and after the experiment.

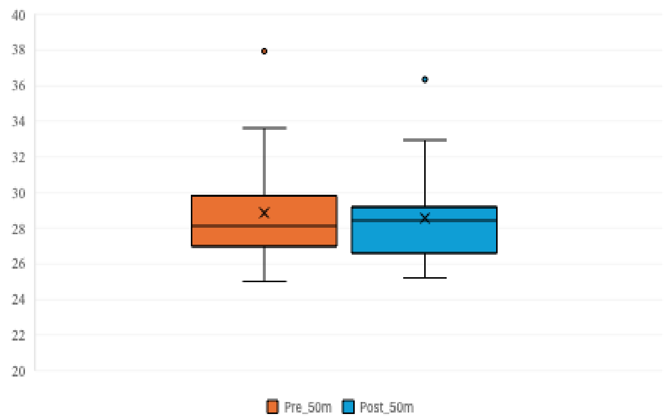

Fig. 1: Boxplot graphs for pre- and post-performance

For the 1RM squat test, athletes in the experimental group (EG) recorded a significant increase in performance, rising from an average of 106.56 ± 33.25 kg to 118.13 ± 31.05 kg (p = .018, t(7) = −3.09). This increase was considered to be of a large magnitude (d = 1.09), indicating clear neuromuscular adaptation.

In contrast, the control group showed a modest increase (from 81.00 ± 28.87 kg to 84.38 ± 27.30 kg), which was not statistically significant ($p = 0.089$, $d = 0.69$). Figure 2 shows the pre- and post-experiment differences.

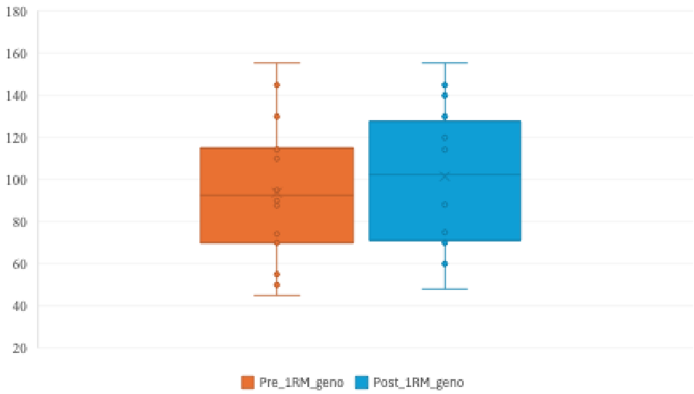

Fig. 2. Boxplot representation of 1RM in the bench press before and after genuflection

In the bench press, the experimental group (EG) progressed significantly from 82.19 ± 21.15 kg to 89.38 ± 27.80 kg ($p = .036$, $d = 0.91$), while the control group (CG) also achieved a significant increase, from 64.75 ± 22.47 kg to 69.94 ± 23.94 kg ($p < .001$, $d = 2.17$). However, the effect was influenced by the lower initial values and sample size. The differences before and after the experiment for the push are shown in Figure 3.

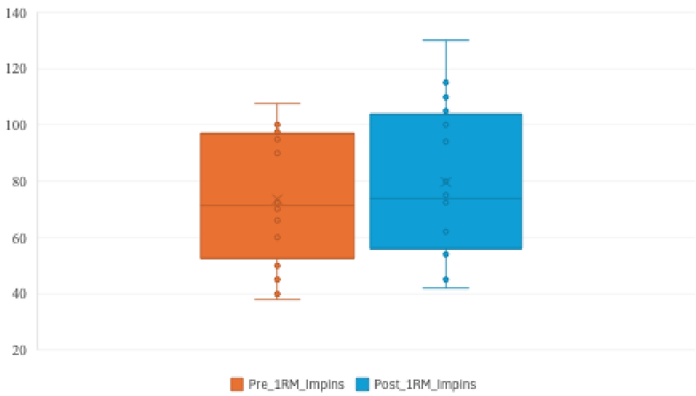

Fig. 3: Boxplot representation of 1RM in the push exercise, before and after.

In terms of speed execution at 60% of 1RM, the experimental group (EG) recorded a significant decrease in squats (from 0.74 ± 0.08 m/s to 0.68 ± 0.10 m/s, p = .011, d = 1.22), which suggests a possible adaptation towards maximum force production at the expense of execution speed. For bench press, however, the change was not significant (0.79 ± 0.22 m/s to 0.82 ± 0.18 m/s; p = 0.39; d = 0.32). In the control group, the results were significant for both the squat and the bench press.

Table 2. Strength and velocity variables (1RM and 60% velocity)

Variable	Pre (M ± SD)	Post (M ± SD)	*p* value	Effect size (Cohen's d)
Experimental Group (EG)				
1RM Squat (kg)	106.56 ± 33.25	118.13 ± 31.05	.018	1.09
1RM Bench Press (kg)	82.19 ± 21.15	89.38 ± 27.80	.036	0.91
Velocity Squat (m/s)	0.74 ± 0.08	0.68 ± 0.10	.011	1.22
Velocity Bench Press (m/s)	0.79 ± 0.22	0.82 ± 0.18	.39	0.32
Control Group (CG)				
1RM Squat (kg)	81.00 ± 28.87	84.38 ± 27.30	.089	0.69
1RM Bench Press (kg)	64.75 ± 22.47	69.94 ± 23.94	< .001	2.17
Velocity Squat (m/s)	0.75 ± 0.07	0.71 ± 0.09	.02	0.98
Velocity Bench Press (m/s)	0.86 ± 0.16	0.77 ± 0.12	< .001	1.95

Note. EG = Experimental Group; CG = Control Group. Significant differences at p < .05.

Overall, the speed-based training programme, which was adjusted using lactate level monitoring and the fixed set speed loss method, produced improvements in maximum strength (1RM). This supports the hypothesis that training controlled by objective feedback promotes significant neuromuscular adaptations, even though the speed at which submaximal tasks were executed did not change proportionally.

DISCUSSION

The main objective of this study was to investigate the effects of a velocity-based training programme (VBT) on performance in the 50 m freestyle (in water start) and on maximum strength (1RM), as well as on execution speed parameters at 60% of 1RM. All of these are associated with a physiological response. The results show that the experimental group experienced significant changes, confirming the initial hypotheses. In the 50 m freestyle with an underwater start, integrating a well-systematised velocity-based programme led to favourable neuromuscular and metabolic transfer. The athletes' neuromuscular capacity showed significant results in the maximum strength tests (1RM squat and 1RM bench press), confirming once again that the programme was successful. An interesting difference between the upper body and lower body was observed in the speed of execution at 60% of 1RM. Values for the bench press remained stable, suggesting that explosive capacity in the upper body was maintained. However, values for squats decreased slightly, possibly due to accumulated fatigue or specific adaptation to maximum strength.

The results obtained are in line with trends in the literature supporting the importance of physical training on land to improve aquatic performance. It was found that performing strength exercises with low to moderate loads and few repetitions per set at maximum execution speeds significantly improved various physical performance variables in elite junior swimmers (Marques et al., 2020). Several studies support the approach taken in this study, namely that high training volumes offer no immediate advantage over lower volumes (with higher intensity) in terms of swimming performance (Aspenes & Karlsen, 2012). Indeed, some studies have demonstrated moderate yet significant correlations between one-repetition maximum (1RM) bench press and short-distance swimming performance (15–50 m) in young competitive swimmers (Garrido et al., 2010). Conversely, testing and improving 1RM bench press and 1RM squat parameters explained 45–62% of the variation in swimming performance, providing further evidence of the importance of maximum strength for short-distance swimmers (Keiner et al., 2019).

The analysis also revealed some unexpected results. One of these was a 60% decrease in 1RM execution speed in the post-intervention tests, particularly for squats. While this decrease could initially be interpreted negatively, a closer look at the increase in maximum strength shows that heavier loads were used, which led to the decrease in speed. Recent research shows that execution speed and the performance level of athletes can affect the correlation with swimming speed (Tan et al., 2021). Furthermore, negative correlations between swimming speed and land-based strength have been observed due to the brief duration of the test (up to 30 seconds), indicating that longer tests may reveal a positive relationship between land-based strength and swimming speed (Morouço et al., 2011). Pareja-Blanco et al. (2016) also demonstrated that using a 20% speed loss threshold results in significant strength gains, in contrast to higher thresholds (e.g. 40%). Therefore, the choice of speed loss threshold should depend on the training objectives. In terms of practical application, the results of this study highlight that using a linear position transducer and lactate testing provides coaches with a complex tool for monitoring athletes' neuromuscular and metabolic responses, helping to prevent overload and optimise intensity. For instance, Wirtz et al. (2014) proposed that the relationship between exercise volume and lactate accumulation is non-linear. The finding that higher lactate levels were recorded during lower body exercises is consistent with previous research showing that larger muscle groups generate a more pronounced metabolic response (Beneke et al., 2002).

In practice, these methods can be applied to any sport in which rapid force production and fatigue control determine performance, such as athletics and cycling. Combining VBT with lactate monitoring can provide guidance for high-performance training, enabling recovery planning and the quantification of physiological stress.

However, there are a number of methodological and contextual limitations to the current intervention that must be acknowledged in order to better understand the scope of the conclusions. The sample size was relatively small ($n = 16$, eight in each group), which limits the generalisability of the results to larger groups of swimmers. A larger sample size would have enabled a more comprehensive statistical analysis and more effective control of variables such as age and experience. Another limitation is that strength and speed tests were performed on land while performance was tested in water, as environmental differences may influence the transfer of neuromuscular adaptations. Including tests performed in water (such as underwater traction force) would provide additional information on adaptation mechanisms. The lack of strict control over diet and sleep may have had a negative impact on lactate levels, neuromuscular recovery and daily physical fitness. Integrating a questionnaire for subjective monitoring of these variables could add validity to the study. However, the statistical significance identified ($p < .05$) and the consistency of the direction of change (increases in strength and decreases in 50 m times) support the validity of the conclusions.

For future research, it is recommended that the intervention is extended in order to analyse its long-term effects on neuromuscular and metabolic adaptations. In addition, a larger and more diverse sample should be included in terms of performance level and age. At the same time, lactate monitoring could be combined with other physiological indicators, such as heart rate, heart rate variability and sleep parameters, to improve our understanding of the adaptation process and other factors.

CONCLUSIONS

In conclusion, integrating a velocity-based training programme monitored by lactate level analysis has proven to be an effective strategy for improving swimming performance. This approach ensures strength development and maintains optimal load and recovery control. It also significantly transfers neuromuscular and metabolic adaptations to specific performance. This confirms the essential role of objective monitoring and individualisation in sports training.

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