ARE DRY-LAND STRENGTH METRICS AND FORCES EXERTED IN-WATER RELATED WITH HIGH SWIMMING VELOCITY IN YOUNG ATHLETES?

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This study aimed to assess strength metrics in 3 dry-land exercises, forces exerted in-water in 3 tethering conditions, and to analyze possible relationships between those variables with high swimming velocity. Mean power, mean forces and 50 m maximum swimming velocity, were recorded and calculated for ten male young swimmers. High correlations were noticed between the dry-land exercises, with the lat pull down presenting the higher correlation with swimming velocity (r = 0.695, p = 0.026). The higher correlation of swimming velocity with forces exerted in-water was observed through the only arms condition (r = 0.762, p = 0.010). Results suggest that for high swimming velocity forces exerted in-water by the arms are a major criteria for success, and that lat pull down may be an appropriate dry-land exercise for its development.

KEY WORDS: power, front crawl, training, testing.

INTRODUCTION: The importance of strength on swimming velocity has long been discussed and main data suggests that the force exerted in water is a major factor for success. For that reason relationships between dry-land exercises with the forces exerted in-water, and ultimately with swimming performance, have been the topic of many studies. For example, Crowe et al. (1999) assessed 1 maximum repetition in 3 dry-land exercises (bench press, lat pull down and triceps press), forces exerted in tethered swimming and performance in short-distance swimming events (50 and 100 m). Their conclusion was that all dry-land exercises were strongly correlated with forces exerted in water, but not with swimming performance. Consequently, it could be questioned why swimmers were not able to effectively apply their force in the water during free swimming. Furthermore, it is unclear if the used methodology (1 maximum repetition) was the appropriate strength metric to associate with swimming performance. Based on the existing literature it seems that there is no consistent evidence regarding these issues. First, doubtful conclusions from heterogeneous groups in swimming have long been recognized (Rohrs et al., 1990), specifically when correlations are estimated. Indeed, most available experiments evaluated heterogeneous samples with participants of different swimming and strength abilities, and some gathering male and female swimmers. Second, it is common to assess the maximum force through a 1 maximum repetition test. This does not take into consideration the velocity of the movement (González-Badillo and Sánchez-Medina, 2010), being uncertain If it is a valid methodology for swimmers evaluation. Third, both strength and power assessments may be useful to understand the importance of power output for swimming performance, and likewise to improve training programs (Newton et al., 2002).
Therefore, the purpose of the present study was to assess power in 3 dry-land exercises and forces exerted in water in 3 tethering conditions, in order to examine possible correlations with sprint swimming performance.

METHODS: Ten young male swimmers (age: 15.9 ± 0.74 years, body mass: 60.0 ± 6.26 kg, height: 171.9 ± 6.26 cm, 100 m long course front crawl performance: 59.9 ± 1.87 s), with at least 4 years of competitive swimming, volunteered as participants. All procedures were in accordance to the Declaration of Helsinki and approved by the Ethics Committee of the hosting University, and were consented by parents and coaches.

Participants performed, randomly, 7 tests: 3 dry-land exercises (lat pull down, bench press, and full squat) for power assessment, 3 maximal bouts of 30 s with the swimmers tethered to a load-cell (whole-body, only arms, and only legs), and 1 maximal 50 m free swimming bout.

Dry-land tests: On separate days participants were tested for lat pull down, bench press and full squat. All tests were performed in a gym starting with 5 min of stationary cycling at a self-selected easy pace, 5 min of static stretches and joint mobilization exercises. Using a dynamic measurement system (T-Force System, Ergotech, Murcia, Spain), each participant executed 2 repetitions (5 min rest) for each load in an incremental workout. A detailed description of the measuring device used in this study has been reported elsewhere (Sánchez-Medina and González-Badillo, 2011). For lat pull down and bench press, initial load was set at 10 kg and was gradually increased in 10 or 5 kg increments until mean propulsive velocity got lower than 0.5 $m.s^{-1}$, for the concentric phase. Same routine was used for the full squat until a mean propulsive velocity lower than 0.8 $m.s^{-1}$ was obtained. These velocities were considered to ensure that the maximum power was reached (González-Badillo and Sánchez-Medina, 2010). For lat pull down a novel fixation method allowed the measurement system to be fixed to the load. For bench press and full squat a smith machine was used to ensure a smooth vertical displacement of the bar along a fixed pathway. Participants were required to always execute the concentric phase of the exercises in an explosive manner, at maximal intended velocity.

In-water tests: The swimmers completed a 1000 m standardized warm up (400 m swim, 100 m pull, 100 m kick, 4 x 50 m at increasing speed, 200 m easy swim) before performing 3 x 30 s maximal intensity fully-tethered front crawl swimming. The trials were performed in a randomized order and were separated by a minimum of 30 min active recovery. For one trial no constrains were applied so that participants could use their whole-body to perform the test. For the other two trials, floating devices (pull-buoys) were used to restrict the movements of legs and arms. Visual inspection concluded that the swimmers were able to keep their streamlines for each condition. Furthermore, during the test with only arms, the participants had their ankles fastened together to prevent from performing the leg kick. All experimental testing was performed in a 50 m indoor swimming pool with a water temperature range of 25.5-27 °C. On a separate day, after the same warm-up, participants performed 3 maximal 50 m bouts of front crawl swimming, with an in-water start.

Data analysis: From the dynamic measurement system, velocity was sampled at a frequency of 1-KHz and subsequently smoothed with a 4th order low-pass Butterworth filter with a cut-off frequency of 10-Hz. Instantaneous power output resulted from the product of the vertical applied force and bar velocity ($P = F.v$). Mean power of the propulsive phase was assessed for each load and the higher value was registered for subsequent analysis. The propulsive phase was defined as that portion of the concentric phase during which barbell acceleration was greater than acceleration due to gravity (i.e. acceleration > $-9.81\ m.s^{-2}$) (Sánchez-Medina and González-Badillo, 2011).

Individual force to time curves were recorded at 100-Hz and exported to a signal processing software (AcqKnowledge v.3.7, Biopac Systems, USA), and filtered through a 4.5 Hz cut-off low-pass filter. The cut-off value was chosen according to residual analysis (residual error versus cut-off frequency). As the force vector in the apparatus presented a small angle to the horizontal, data were corrected by computing the horizontal component of the force. Mean values were registered for subsequent analysis.

The swimming velocities were estimated according to $v50 = 50.\Delta t^{-1}$; where Δt was the mean of the chronometric time in the 3 bouts.

For reliability study, 6 swimmers replicated the tethered swimming tests one week later. The normality and homogeneity of all distributions was verified using Shapiro-Wilk and Levene tests, and parametric statistical analysis was adopted. Pearson correlation coefficients (r) were determined to assess the relationships among selected variables, and linear regression analyses were applied to evaluate the power of the associations.

RESULTS: Intraclass correlation coefficients ranged between 0.94 (0.91 to 0.98) and 0.98 (0.96 to 0.99) for the power and force measurements. The higher mean power of the propulsive phase was obtained in the full squat, followed by lat pull down and bench press (381.8 ± 49.7, 271.3 ± 47.6 and 221.8 ± 58.6 W, respectively), with strong and very strong correlations between exercises (cf. Figure 1.). Mean force exerted in-water using only arms was 85.7 ± 8.2 % of the correspondent variable assessed with the whole-body, and with only legs swimmers attained 35.1 ± 4.8%. Significant correlations were observed between forces measured using the whole-body and with only arms (*r* = 0.780, *p* = 0.008), and using only legs (*r* = 0.823, *p* = 0.003).

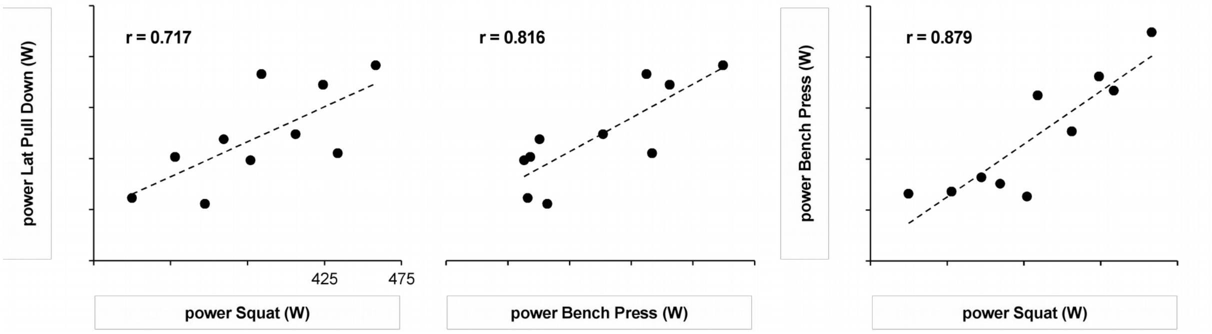

Figure 1: Relationships of the higher mean propulsive power between the dry-land exercises.

Swimming velocities (1.69 ± 0.04 $m.s^{-1}$) were found to be positively correlated with both the mean power of the propulsive phase obtained in the lat pull down and the mean force exerted in-water using only arms (cf. Figure 2).

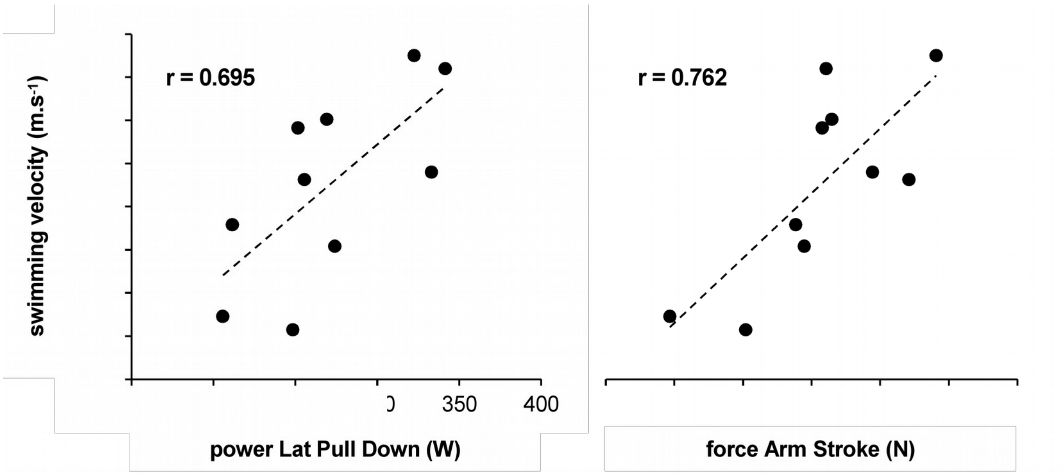

Figure 2: Relationships of swimming velocities with power assessed in lat pull down and forces measured in the water with only arms.

DISCUSSION: Although some studies have reported significant relationships between dry-land exercises and forces exerted in-water (e.g. Johnson et al., 1993; Crowe et al., 1999), the association between dry-land exercises and swimming performance has never been clearly established. The current study does not come up with a definite solution to that matter. However, it does provide some valuable evidences in terms of the importance of strength for sprint swimming performance. This was the first study assessing the mean power of the propulsive phase in 3 dry-land exercises, and to relate it with swimming performance. The lat pull down exercise, performed explosively, came out to be the one with higher relationship with swimming velocity. Plus, for the studied swimmers, forces exerted in-water with only arms stood up as the main criteria to explain performance, suggesting that arms strength is the major criteria for sprint swimming performance.

In a similar approach to the present study, Johnson et al. (1993) stated that whatever the contribution dry-land strength/power makes to swimming performance, it is reflected in the results obtained in tethered swimming. Thus, the inclusion of dry-land measures to evaluate swimmers would be redundant. These statements neglected the velocity of the execution in the dry-land exercises, and consequently we may question whether the measurement of one repetition maximum is an appropriate methodology to evaluate swimming specific movement strength. With that in mind, we followed the recommendations of González-Badillo and Sánchez-Medina (2010) who stated that mean power of the propulsive phase should be considered as it is the most stable parameter, lending further support to its preferential use in strength and power assessment. As a result, not only strong relationships among dry-land exercises were obtained, inducing that the used methodology can be used to assess dry-land power independently of the performed exercise, but also that the lat pull down stood up as the dry-land exercise more associated with high swimming velocity. Furthermore, swimming velocity was more associated with forces exerted with only arms; reinforcing the significance that strength has for sprint performances (Morouço et al., 2011).

CONCLUSION: Coaches aim to reach an optimum balance between strength and technique for their swimmers training. In fact, strength should reach an optimum and individualized magnitude, without bringing disadvantageous consequences (e.g. hypertrophy) (Newton et al., 2002). A systematic assessment of both power in dry-land exercises and forces exerted in-water may provide the necessary information for the training prescription. For instance, forces exerted in the water using only the arms were ~15 % lower than using the whole-body. If a swimmer increases his power in the lat pull down exercise and simultaneously in the mentioned percentage, that swimmer is not being able to effectively apply his force in the water. Thus, it may represent situations where strength development might not lead to a gain in performance, as the necessary coordination would be deficient.

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OPTIMISING MECHANICAL POWER OUTPUT IN WEIGHTED BACK SQUATS - A JOINT LEVEL ANALYSIS

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When performing resistance training to improve muscular power output it is desirable to train with a resistance that maximises mechanical power. Previous studies investigating what resistance maximises power output show varied results and generally lack mechanistic conclusions. To address this we studied the whole-body and lower-limb joint mechanics of weighted back squatting. Ten male rowers performed maximal power squats with an Olympic bar and weights equivalent to 0, 10, 20, 40, 60 & 80% of their 1 RM. Whole-body power did not peak at a single resistance but over the range of 20-60%. This was owing to a trade-off in knee and hip powers that were maximised at 20% and 60%, respectively. When determining training resistances, practitioners should consider what joint powers should be emphasised in relation to the mechanics of the target sport.

KEY WORDS: resistance training, inverse dynamics, joint moment, joint velocity

INTRODUCTION: Developing greater muscular power output is a key goal of athletic training programmes for many athletes. Typically, a part of this programme will include resistance training in the form of weight lifting exercises. It has been shown that to achieve the greatest improvements in muscular power output, the training task should be performed against the resistance that maximises power output (Kaneko, Fuchimoto, Toji & Suei, 1983). Therefore it is desirable to know what level of resistance will result in maximal power production. As a result this topic has received considerable attention in the literature but these studies have produced greatly varied results reporting maximal power production to occur anywhere between 0 and 60% dependent on the exercise (Baker, Nance & Moore, 2001; Cormie, McCaulley, Triplett & McBride, 2007). In terms of lower limb exercises the two most prevalent are the squat and jump squat with maximal power being developed at low resistances for the jump squat and typically near 50-60% of 1 repetition maximum (RM) for the squat (Cormie et al. 2007, Bevan et al. 2010). However, peak power for the optimal resistance in these studies was not significantly different from peak power for a large range of resistances surrounding the optimal resistance. It has been shown that this optimal range of resistances for power production is dictated by a trade-off in movement velocity and net external forces (Cormie et al. 2007). However, these velocities and forces only represent the overall net effect of all muscles that are acting in a coordinated fashion through joints to effect the movement. Breaking down squatting mechanics to a joint level could reveal more about the mechanisms dictating the optimal resistance for power production in squatting and elicit why a singular optimal value has not been observed.

Flanagan and Salem (2008) quantified lower limb net joint moments and the work done by those moments during back squats with varied resistance but without the aim of maximising power. They showed that the proportion of total work contributed at each joint varied with level of resistance. As added weight increased, a greater proportion of work was provided at the hip with a lesser contribution at the knee. The ankle's contribution was never more than 10%. This highlights that the total work output is not solely dependent upon the force-velocity properties of lower limb muscles but also is influenced by a control strategy that changes with the external resistance. It is therefore important to investigate the contributions made at individual lower limb joints to power output during maximal power squatting to understand the relationship between resistance and total power output.

The aim of this study was to break down mechanical power output during weighted back squats performed over a range of resistances from the whole-body level to that of individual lower limb joints. We hypothesised that total power output would be maximised over an