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Effect on swimming start performance of two types of activation protocols: lunge and YoYo squat.

Brief Running Head: PAP in Swimming Starts: Lunge Vs YoYo Squat

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ABSTRACT

The purpose of this study was to compare the effects of two protocols of post-activation potentiation (PAP) on swim start performance (SS).

Fourteen trained swimmers (10 men and 4 women) volunteered for this study. An intra-group design of randomised repetitive measurements was applied. A previous SS trial, performed after a standard warm up (SWU), served as a reference. Two methods of PAP, performed after one hour of rest, were

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randomly added to the SWU: i) three lunges at 85% of 1 repetition maximum (LWU), and ii) four repetitions on the flywheel device YoYo squat (YWU). Swimmers were tested in an SS eight minutes after the PAP warm-ups. Kinematic variables were collected using three underwater digital video cameras fixed poolside and operating at 25 Hz, and one high speed camera focused on the block and operating at 300Hz. Data obtained from the video analysis were processed using a repeated measures analysis of the variance.

The mean horizontal velocity of the swimmer's flight improved after both PAP methods, with the greatest improvement after YWU ($F_{2,12} = 47.042$, $p < 0.001$; SWU= 3.63 ± 0.11; LWU= 4.15 ± 0.122; YWU= 4.89 ±0.12 m/s). After YWU, it took the subjects less time to cover a distance of five meters ($F_{2,12} = 24.453$, $p < 0.001$) and fifteen meters ($F_{2,12} = 4.262$, $p < 0.04$). Subjects also achieved a higher mean angular velocity of the knee extension ($F_{2,12} = 23.286$, $p < 0.001$) and a reduction of the time on the block ($F_{2,12} = 6.595$, $p < 0.05$).

These results demonstrate that muscle performance in the execution of an SS is enhanced after a warm up with specific PAP protocols. YWU leads to the greatest improvement in the performance of the swimmer's start and, therefore, may be especially beneficial in short events.

KEY WORDS: Flywheel, Warm up, PAP, Dynamic Stretching, OSB11 Block

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INTRODUCTION

Swimming start performance (SS) is an important component of the swimming race, especially in short events (8). It consists of explosive movements intended to propel a swimmer from the starting block into the water (9, 42). Among male elite swimmers, swimming start velocities are on the order of 1.8 to 2 m/s, while typical average velocities over the first 15 m of the race are approximately 3 m/s (8, 12).

Many studies have shown improvements in the execution of sporting performances after warming up (3, 6, 7, 25, 31). However, a method called post-activation potentiation (PAP) has recently received considerable attention (15, 19, 34, 35, 41). PAP improves muscle contractility, strength and speed in sporting performances by applying maximal or submaximal loads on the muscle prior to the performance. The effects observed with PAP are the result of a physiologic alteration that renders actin-myosin myofibril more sensitive to Ca^{2+}, released from the sarcoplasmic reticulum, and an increase in muscle fibre recruitment, due to an intensification of the motor-neuron's excitation. This leads to an amplification of the muscle action potential, which improves the mechanical power and, consequently, the athletic performance (15, 19, 34, 35, 41).

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PAP has been shown to be more effective in lower limbs when a rest period of 8 minutes is included after a submaximal stimulus application (24, 29, 39) because the optimum performance occurs when the fatigue has dissipated and the enhancement still exists (39); when it is applied to trained subjects or individuals with a high proportion of fast fibres (16, 19, 30, 33, 34); and when the PAP movement is biomechanically similar to the real movement (16, 35). The use of the new Olympic OSB11 block (OMEGA, Zurich, Switzerland), which consists of a rear plate where swimmers can push with the rear foot, should therefore be considered when choosing an optimal activation exercise that is biomechanically similar to this movement (1, 13, 38).

Few studies to date have examined the SS performance using different types of warm-up, and those that exist, were conducted without a specific stimulus to the lower limbs of the subjects (3, 9, 24). Moreover, no studies have been conducted to assess the effects of warm-ups on SS performance from the new block, where the legs have an asymmetric placement. Thus, there is an urgent need to identify asymmetric potentiation exercises that can provide a stronger and more specific stimulus. The lunge exercise, for example, primarily activates the hip and knee extensor muscles of the front leg (11, 21) and, in track starts, causes the biggest impulse (20). The flywheel inertial device, YoYo squat (YoYo™ Technology AB, Stockholm, Sweden), on the other hand, draws on inertial systems to induce potentiation and, as has been reported in many EMG studies, leads to very high muscular activation (11, 25, 26, 27, 42). A potential benefit of flywheel inertial devices is that the resistance is independent of gravity. As such, the resistance can be applied from any direction, allowing

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for a wide variety of exercises (11, 26, 27, 28, 42). Because it is necessary be attached to a belt that emerges directly from the device, potentiation movements can also be applied with almost the same forward extension movement that the swimmer must perform on the block, thus avoiding falls.

The aim of this study was to compare the effects of two activation protocols for lower limbs on the variables that affect the swimming start. Two warm up protocols were tested for induction of PAP: the lunge exercise, with maximum repetitions, and the YoYo squat flywheel inertial device, with maximum repetitions. These two protocols were compared to a standard warm up protocol. We hypothesised that PAP inducement using the flywheel inertial device would be the most appropriate warm up for optimal performance in a swimming start.

METHODS

Experimental Approach to the Problem

A repeated-measures counterbalanced design was used in which swimmers performed two different activation protocols before performing an SS, after eight minutes of rest. As a control, all participants first performed an SS after a standard warm up (SWU), which consisted of a varied swimming warm

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up followed by dynamic lower limb stretching. Swimmers were then randomly separated into two groups. The first group performed the lunge activation protocol (LWU), which consisted of completion of a SWU followed by PAP inducement with 1 set of 3 lunge repetitions at 85% 1RM. The second group performed the YoYo squat activation protocol (YWU), which consisted of completion of a SWU followed by PAP inducement with 1 set of 4 repetitions at maximal voluntary contraction on the YoYo squat flywheel device. The 4 repetitions on the YoYo squat flywheel device are necessary because the first repetition serves to charge the flywheel. To avoid a "fatigue/learning" effect, the group order was reversed in later tests. Three tests were carried out with one-hour break between each.

Prior to the study, each participant was pretested in the pool with a timed 15m swim, visited the laboratory to become familiar with the testing methods, and had their 3RM lunge measured (values = 77.1 ± 23.4 kg). During these sessions, swimmers also practiced the characteristic forward extension movement of the SS performance on the flywheel inertial device**.**

Subjects

Fourteen trained swimmers (10 men and 4 women; height 176.3 ± 9.1 cm; weight 69 ± 11.4 Kg) volunteered to take part in this study after being informed of all risks, discomforts and benefits involved. All volunteers, from

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whom written informed consent and parental approval had been obtained, were members of swimming clubs in Granada (Spain), between the ages of 17 and 23 and federated swimmers with at least 5 years of participation in national competitions. The university ethics committee approved the study.

Procedures

Prior to data collection, all subjects attended three training sessions on the YoYo squat flywheel inertial device. In these sessions, the RM values for the lunge were also obtained using a Multipower device (Technogym, Spain) according to the guidelines set by *National Strength and Conditioning Association* (21). In these sessions, swimmers also gave their informed consent, and basic anthropometric measures were taken. These training sessions were conducted in the Physical Education and Sports Department, University of Granada (Spain), which is equipped with a Multipower device (Technogym, Spain). The experimental setting was the Olympic pool at the High Altitude Training Centre, National Sports Council (Sierra Nevada) in the city of Pradollano, (Granada, Spain), which is equipped with the OSB11 block (OMEGA) and the flywheel inertial device (YoYo™ Technology AB, Stockholm, Sweden), in the biomechanics lab.

Swimmers reported to the experimental setting on the morning of testing after having refrained from alcohol, caffeine, and strenuous exercise for the

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previous 48 hours. In the morning, between 9:00 and 15:00, after a standardised meal and fluid intake, swimmers performed three warm-ups with an hour break between each of them. Swimmers were allowed to drink water during the entire session.

Reference points were marked on the joints of the hip, knee and ankle of swimmers on arrival. The swimmers were informed about the testing day procedures. Each time the swimmers completed a warm up protocol, they had a rest period of 8 minutes after which they performed a competition SS at maximum speed. There was only one performance for each test to simulate the conditions of a competition "attempt" (*FINA rules*). During the entire session, there was an assistant who monitored the resting time for each subject. The starting signal was an auditory stimulus, in this case the one usually used in competitions. In each trial, the subject was requested to mount the block. When in position, the subject was given the verbal command "take your mark", and shortly afterwards, the starting signal was sounded. After recording the trial, swimmers rested for an hour.

All swimmers first performed the standard warm up (SWU) that included 400 m of varied swimming consisting of: 200 meters easy freestyle swim with two starts from the wall (one of them to get into the water, and the other after 100 meters); 1 x 50 m front crawl swim (12'5 fast / 12'5 smooth); 1 x 50 m front crawl swim at race pace; and 100 meters front crawl at a normal pace. To establish a sufficient time interval between one swimmer and the next, each swimmer began the warm up when the previous swimmer was performing the

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second start of the first 200 meters of the warm up. After swimming, the participants began their dynamic stretching protocol, which consisted of: forward leg swings, ankle dorsi- and plantar-flexion, side leg swings, high knees, heel flicks, squats and lunges. Each exercise was performed 10 times, and the entire set was repeated twice (1 set per min). Dynamic stretches were designed to have an effect on the musculature most closely related to the jump performance. An independent researcher monitored the entire stretching set to ensure that the stretching exercises were performed properly and at the right pace during the 4 minutes. After 8 minutes of rest, the swimmers performed an SS.

Next, swimmers were randomly divided into two groups of 7 people each. The first group performed the warm up with the lunge repetitions (LWU). This consisted of warming and dynamic stretching, as in the SWU, followed by the PAP stimulus that consisted of lunge exercises performed in a Multipower machine (Figure 1). The position of the exercise was monitored to ensure compliance with the rules of the *National Strength and Conditioning Association* (21). In the starting position, the rear knee was placed on a lifted surface 5 cm from the ground so that the leg and thigh formed a 90 degrees angle, while the foot of the front leg was placed entirely on the ground so that this leg and thigh also formed a 90 degrees angle. When this position was set, the leg extensions were performed. To ensure consistency in the positioning of the front leg, swimmers placed their legs in the same position that they used to perform the swimming starts. All swimmers performed three repetitions at maximum speed to 85% of 1RM. During the entire exercise, a study collaborator monitored the

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initial position and the specific loads of each subject. After 8 minutes of rest, swimmers performed a swim start. The second group performed the warm up with repetitions in the YoYo squat flywheel device (YWU). This consisted of warming up and dynamic stretching as in SWU, followed by the PAP stimulus that consisted of repetitions on the YoYo squat flywheel device (Figure 2). The starting position modelled the position used by the swimmers on the block in a swimming start performance, with the same front and rear placement of the legs. After attachment of the belt, swimmers performed 4 maximum intensity repetitions, with the first repetition serving to charge the flywheel. During the entire exercise, a study collaborator monitored the initial position and provided swimmers with device harnesses. After 8 minutes of rest, the swimmers performed an SS.

(FIGURE 1 ABOUT HERE)

(FIGURE 2 ABOUT HERE)

The third trial was carried out in the reverse order. The first group performed the YWU activation protocol and the second group performed the LWU activation protocol. After 8 minutes of rest, swimmers performed an SS.

Kinematic Measurements

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Dive Distance (DD): The distance from the swimming pool wall, under the starting block, to the first contact of the swimmer's fingers with the water (m) (22).

Flight time (FT): The time between the last contact of the feet with the starting block and the first finger contact with water (s) (22).

Mean Horizontal Hip Velocity (VxH): The horizontal hip distance during the flight, from the last contact of the feet with the starting block to the first finger contact with water, divided by the time elapsed for this action (m/s) (2).

$$VxH = \frac{x}{t1 - t0}$$

Time to 5 meters (T 5m): The time elapsed from the when the strobe light flashed until the head arrived at the vertical 5 meter line (s) (2).

Time to 15 meters (T1 5m): The time elapsed from when the strobe light flashed until the head arrived at the vertical 15 meter line (s) (2).

Angle of Take-off (AT): The angle between the horizontal line and the line which connects the body's centre of mass with the reference spot on the foot, at the moment of the last contact of the foot with the starting block (degrees) (36).

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Angle of Entry (AE): The angle between the horizontal line and the line which connects the body's centre of mass with the reference spot on the hand, at the moment of the first contact of the fingers with the water (degrees) (36).

Block Time (BT): The time elapsed from when the strobe light flashed until the moment that the swimmer was separated from the block (s).

Mean Angular Velocity of Knee Extension (VωK): The knee's angular difference between the moment of maximum extension and the moment of maximum flexion ("ready"), divided by the time elapsed for the performance of that extension (rad/s).

$$V\alpha = \frac{\alpha 1 - \alpha 0}{\mathbf{t1} - \mathbf{t0}}$$

Data collection for swim starts. Each trial was recorded with four digital video cameras. One camera was a high-speed camera (Casio, HS Camera 300Hz) that operated at a sampling rate of 300Hz. This camera, which was mounted on a tripod and focused on the block, recorded the BT, AT and VωK. The three other digital video cameras (Sony Video Camera, 50Hz) were focused on the poolside. One of them recorded the block phase, another one recorded the underwater phase to 5m and the last one recorded the swim phase to 15m.

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These three sequences were overlapped in space and time by a video switcher (Digital Video Switcher SE-900). These cameras also recorded the DD, FT, VxH, AE, T5m and T15m. The shutter speed was adjusted using a modality (Sport Mode) that maximised the shutter speed within the limits of the cameras being used (1/4,000 seconds), thereby minimising any distortion within the movement of the swimmers. Both block cameras were focused on the starting system to detect the light emitted by the starting signal. The starting system (Signal Frame, Sportmetrics) simultaneously emitted an audible signal and a strobe flash; this was used to synchronise the starting signal with the video image. All video files were analysed by two different researchers with the Kinovea®, version 0.7.10., software, which allowed for the analysis of the reference points drawn on the swimmers.

Statistical Analysis

Statistical analysis was performed using SPSS Version 21.0 (IBM, Chicago, IL, USA). Descriptive statistics of the data were expressed as the mean ± the standard deviation (SD) and the 95% confidence interval. The test-retest reliability (intraclass correlation coefficient [ICC]), within and between observers, was analysed for each of the variables.

After testing for the normality distribution, the analysis was carried out using a repeated measures ANOVA to determine the differences in SS

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performance within and between the subjects, after warm up with the three protocols. To detect differences between protocols, significance was accepted at the *alpha* < 0.05 level and paired comparisons were used in conjunction with Holm's Bonferroni method to control for type 1 errors.

To assess the reliability of the digitising process (intra- and inter-observer), six trials were quantified using intra-class correlation coefficients (ICC), three of them were digitised by the researcher and the other three by an investigator with experience in the Kinovea® software digitisation management. These correlations were calculated separately, for the repeated measures of all the variables, from 6 randomly chosen subjects. The intra-observer ICC ranged from 0.97 (95% confidence interval (CI) 0.96-0.98) to 0.99 (95% CI 0.98-0.99); and the inter-observer ICC ranged from 0.98 (95% CI 0.97-0.98) to 0.99 (95% CI 0.99-0.99). These results show a high correlation and reliability.

RESULTS

Mean, standard deviation and confidence interval for all variables studied are summarised in Table 1.

The repeated measures ANOVA analysis revealed significant differences for DD ($F_{2,12} = 35.861$, $p < 0.001$) between the three warm up protocols, and DD

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was highly significant after protocols with PAP inducement ($p < 0.01$) compared to the control. The distance to entry in the water was longer for YWU (304.28 ± 9.066 cm) and LWU (300.29 ± 8.654 cm) compared to SWU (294.2 ± 8.679 cm).

Significant differences in FT were also observed ($F_{2,12} = 69.491$, $P < 0.001$) after YWU compared to SWU ($p < 0.001$), and after YWU compared to LWU ($p < 0.01$). Mean times for YWU (0.28 ± 0.13 sec) and LWU (0.31 ± 0.14 sec) were shorter compared to SWU (0.33 ± 0.14 sec).

(TABLE 1 ABOUT HERE)

The mean values recorded for VxH (during flight) were significantly different between the three warm up protocols ($F_{2,12} = 47.042$, $p < 0.001$). Swimmers were faster during flight after the YWU activation protocol (4.89 ± 0.12 m/sec) compared to the other two protocols (Table 1). The VxH was also significantly higher ($p<0.001$) after LWU (4.15 ± 0,122 m/sec) compared to SWU (3.63 ± 0.11 m/sec).

The T5m was significantly different between the three warm up protocols ($F_{2,12} = 24.453$, $p < 0.001$; YWU and LWU, $p < 0.001$; SWU, $p \leq 0.001$), where the mean time was shorter for YWU (1.65 ± 0.052 sec) compared to LWU (1.71

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± 0.053 sec), and both were shorter when compared to SWU (1.75 ± 0.057 sec). LWU was significantly shorter compared to SWU ($p = 0.03$). In contrast, for T15m, only YWU and SWU were significantly different ($F_{2,12} = 4.262$, $p < 0.04$), with mean values of 7.54 ± 0.23 sec after SWU, and 7.36 ± 0.22 sec after YWU ($p < 0.05$).

No differences were found for AE ($F_{2,12} = 0.246$, p = not sig.) and AT ($F_{2,12} = 0.457$, p = not sig.) between the three warm up protocols (Table 1).

Although differences were found for BT ($F_{2,12} = 6.595$, $p < 0.05$), pair comparisons only revealed differences between SWU and YWU ($p < 0.05$), with shorter mean values recorded after YWU (0.741 ± 0.022 sec) compared to the mean values recorded after SWU (0.792 ± 0.019 sec).

Statistical analysis for VωK revealed significant differences between protocols ($F_{2,12} = 23.286$, $p < 0.001$). Mean values recorded after execution of the flywheel device (YWU) were significantly different compared to both SWU ($p < 0.005$) and LWU ($p < 0.001$). The mean knee extension velocity was highest for YWU (107,41 ± 4,89 rad/sec) in comparison with the two other warm up protocols (Table 1).

DISCUSSION

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The aim of this investigation was to compare the effects of two activation protocols for lower limbs on the variables that affect swimming start performance. Two specific ways of inducing PAP during the warm up were studied: three maximum repetitions in a lunge exercise, and four maximum repetitions in a YoYo squat flywheel inertial device. These two methods were compared to a standard warm up method. We hypothesised that an activation protocol that induced PAP using the flywheel inertial device would be the most appropriate warm up for an optimal performance in a swimming start, and our results demonstrated that, indeed, YMU had the greatest enhancement on swimming start performance.

To improve SS, two activation protocols were added to the standard warm up. This activation should be applied to the lower limbs because, according to several studies in elite swimmers (5, 18, 36, 44), there is a clear relationship between the propulsive actions of the legs and a good SS performance. The first protocol (SWU), which was established as the control, consisted of varied swimming, followed by dynamic lower limb stretching. This protocol was based on the performance improvement after physical warming that was previously shown by many authors (3, 6, 7, 25, 31), and on the demonstration that dynamic stretching protocols can improve the range of motion and explosive executions in swimmers (4, 10, 31, 35, 39). We decided to combine both aspects, physical warming and dynamic stretching, to provide

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specific stimuli and, thereby, enhance the effects achieved during warm up as previously reported by Fletcher (17) and Samson (35).

In the LWU, the swimmers performed the same warm up as in the SWU, which was then followed by PAP induction through a lunge repetition performed at 85% of 1RM. This protocol was based on the study of Kilduff et al. (24), which compared the effects of a warm up and an activation protocol, based on PAP, on swimming starts. In that study, the authors found similar results after both the warm up and after PAP, but they did not investigate whether the addition of PAP to the warm up would be able to potentiate the stimulus or, in contrast, generate fatigue, which could counteract or even exceed the potentiation. Till and Cooke (40), reported that their participants did not react to the PAP because they were not able to recover after the PAP stimulus. In this study, although the load was heavy enough to cause activation, the short rest time did not allow the fatigue to be dissipated. For this reason, both appropriate load and rest were considered in our study. In the study of Kilduff et al. (24), PAP was induced by the squat exercise at 87% of 1RM. In our study, however, PAP was induced by the lunge exercise to provide a stimulus to the lower limbs that was biomechanically similar to the movement used in the new starting blocks (16) and that also considered the benefits of the free weight exercises used in the study of Kilduff et al (24). During the lunge exercise, the front leg is mainly potentiated due to the asymmetry of the leg placement (11). According to the asymmetry study of leg arrangement carried out by Hardt et al. (20), the front leg causes the greatest impulse in track start.

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In the YWU, the swimmers performed the same warm up as in the SWU, which was then followed by PAP induction through four repetitions on the YoYo squat. The application of this activation system was an innovative aspect of our study because we have not found any reference to its use in swimming. The use of the YoYo squat was based on two clear objectives: to take advantage of the characteristics of the system to provide an activation movement that was biomechanically identical to the real action (16), without a risk of falling; and to generate, during the first repetition of each set, a high lower limb activation, due to the high requirements of power and strength in the concentric and eccentric phases (11, 26, 27, 28, 42). In several studies, the load is applied in accordance with a previous test of RM. However, throughout the entire process, subjects may vary their performance due to either a deterioration or an improvement in their skills, or because the load was not obtained properly. This problem is resolved with the use of the YoYo squat because the resistance is proportional to the force applied. Hence, maximal performance can be achieved regardless of a subject's condition on the day of the test (11).

To assess the effectiveness of a swimming start, the analysis of the VxH is imperative because it accurately expresses the changes that occur in a swimmer's performance in distance, time, or both. We observed that VxH ostensibly improved after YWU (4.89 ± 0.12 m/sec) compared to LWU and SWU (Table 1). This means that the swimmer's flight was longer and faster, as confirmed by the increased DD and the decreased FT (Table 1). There was also

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a significant improvement in these variables after LWU compared to SWU (VxH, $p < 0.001$; DD, $p < 0.001$; and FT, $p = 0.004$; Table 1). These results imply that activation protocols based on a PAP inducement can have positive effects on the participants during the first phases of the swimming start, after take-off. It is not possible to compare our results with those obtained by Kilduff et al. (24) because of differences in the activation protocols and variables recorded, such as horizontal and vertical peak forces recorded by Kilduff et al., which improved after PAP inducement. However, our results are clear evidence that an improvement in the peak forces occurred on the block. Several studies have reported that PAP inducement significantly improves peak forces due to the recruitment of fibres caused by maximal or submaximal voluntary muscular contractions (10, 15, 23, 24, 34, 39, 41). This leads to an increase in the velocity of the nerve fibre conduction and an increase in EMG activity. In explosive movements, such as jumping or an SS, this can lead to an increase in the height or distance, and jumping power. These results are in agreement with those obtained by Breed and Young (9), who assessed the effects of a specific resistance training that focused on SS and found that the improvement in the strength applied to the block was correlated with the improvement in the hip velocity during flight ($p < 0.05$).

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T5m was shorter after the YWU protocol compared to that recorded after the LWU and the SWU protocols (Table 1). There was also a slight difference ($p < 0.05$) between the values obtained after the LWU protocol compared to the SWU protocol, indicating that the LWU protocol is more effective (Table 1). The reduction in the recorded time was caused by the enhanced flight phase, as

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discussed above (5). The potentiation in take-off ensures that swimmers enter the water with higher velocity, which can be used in the initial underwater gliding.

The results for T15m, show that the time was slightly decreased after the YWU. This supports the results previously obtained by West et al. (44) and Seifert et al. (35), where the best SS, defined as the time to 15 meters, was correlated with the strength and power in the subject's lower limbs, which enabled development of a higher velocity at take-off. However, we observed significant differences only between the YWU and the SWU protocols ($p < 0.045$; Table 1); the differences between the LWU and the two others protocols were not significant. These results could be because swimming to 15 meters depends on other technical aspects, such as the power of the initial strokes or the effectiveness of undulatory swimming. For example, in the study of Elipot et al. (14), swimmers began the underwater kicks as soon as possible to gain speed. However, this caused an increase in the drag and, consequently, a loss of velocity. Swimming to 15 meters could, in addition, have generated a level of fatigue that was higher than the potentiation, (40) thus requiring more rest time. On the other hand, the load applied may have been insufficient. Future studies should clarify this matter. Our results, from the PAP induction to the free weight exercises, were similar to those obtained by Kilduf et al. (24), and although T15m did not increase or worsen, there was no significant improvement after PAP induction with the lunge.

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The mean values obtained for VωK and BT were better after the YWU protocol compared to the other two protocols. The results for VωK indicate a better performance after the YoYo squat warm up protocol (YWU vs. SWU, $p < 0.01$; YWU vs. LWU, $p \leq 0.001$) due to the higher velocity of the knee extension compared to the others protocols (Table 1), thus, enabling the swimmers to leave the block earlier. These results are in agreement with those obtained by Yamauchi and Ishii (45), who studied the relationships between force-velocity and vertical jump after resistance training for lower limbs. They concluded that the improvements gained in vertical jump were caused by a higher extension velocity of the knee, which was a consequence of the improvement in the power generated. In our study, the block phase of the swimmers was better after YWU because they were able to combine a shorter time on the block with a higher force production (9). This combination could be because the back leg was also potentiated during the YoYo squat executions, and according to Arellano et al. (1), the back leg provides a larger impulse on the new OSB11 block. It is not clear why such low mean VωK values were recorded after LWU (Table 1). Vertical jumping has been commonly used to improve swimming starts, and studies have shown an improvement after vertical movements (5, 9, 32). However, a recent study by Rebutini et al. (32), where they found an improvement in the SS performance after a plyometric horizontal training, but not after a plyometric vertical training, is consistent with our low VωK values after LWU. Rebutini et al. concluded that enhancements to SS performance were caused by an increase in the rate of force development by the hip and knee due to the specific training. This suggests that the enhancement of general muscle performance is not sufficient to enhance overall performance.

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Rather, training for a specific skill is critical to achieving that goal because it ensures the control and training of the essential resultant force vectors. On the other hand, it is possible that the initial angle of the front knee of the swimmer was suboptimal for the required force production. In the study of Slawson et al. (37), they showed that, in SS, the optimal knee angle of the front leg should be fixed between 135 and 145 degrees. It is possible that our subjects started with a knee angle greater than 145 degrees. Nevertheless, the balance between fatigue and potentiation generated may be the key to this issue and should be investigated in the future.

We observed a reduction in the time on the block (decreased BT) after YWU (0.741 ± 0.022 sec) compared to SWU (0.792 ± 0.019 sec), which may explain the dramatic improvement in VωK that we also observed. After YWU, the swimmers left the block earlier because their leg extension was faster. The BT observed after LWU was not significantly different compared to the other two protocols (Table 1), although the mean values were not longer than those obtained after SWU. These results are consistent with those observed for VωK after LWU. Because there is no improvement in the velocity of the extension of the legs, there is no a reduction in the time on the block.

Neither AE nor AT were altered after any protocol (Table 1). Consequently, we can conclude that the technical aspects remained unchanged, and improvements in performance can be explained by the effects

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of different warm up or activation protocols on the swimmers and not by technical variations in the execution of the SS.

In conclusion, the warm up protocols evaluated in this study, which included a specific PAP application, showed better results than the standard warm up. Specifically, the application of the flywheel inertial device (YWU) is the most appropriate warm up for optimal performance in a swimming start because it can enhance SS and may be especially relevant in short events.

PRACTICAL APPLICATIONS

Our study is important and relevant for the application of a system that can be used in the field of aquatic sports to enhance explosive movements, such as swimming start performances, which have been shown to improve the overall performance of swimmers, especially in short events. The benefit of the YMU protocol on start time and the increase in angular velocity of the knees leads us to recommend this protocol prior to competition in short events. The optimum performance occurs when the fatigue has dissipated and the enhancement is still present; therefore, improving the resistance to fatigue is an important consideration for coaches because this will allow for greater enhancement of performance after PAP. Although adaptation of this protocol to meet competitive constraints needs to be resolved in the future, its ability to

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improve the power applied during the first pulling strokes is an important subject and should be studied further.

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TABLE

Table 1. Mean, standard deviation and confidence interval of spatio-temporal and angular variables in the three different activation protocols (n=14).

	Protocol 1		Protocol 2		Protocol 3	
	Mean ± SD	CI (95%) LL UL	Mean ± SD	CI (95%) LL UL	Mean ± SD	CI (95%) LL UL
DD (cm)	294.20 ± 8.67#	275.45-312.95	300.29 ± 8.65	281.59-318.98	304.28 ± 9.06*	284.62-323.79
FT (sec)	0.33 ± 0.14#	0.30 - 0.36	0.31 ± 0.15$	0.27 - 0.34	0.28 ± 0.13*	0.25 - 0.31
VxH (m/s)	3.63 ± 0.11#	3.38 - 3.88	4.15 ± 0.12$	3.89 - 4.42	4.89 ± 0.12*	4.62 - 5.17
T5m (sec)	1.75 ± 0.05#	1.62 - 1.87	1.71 ± 0.05$	1.59 - 1.82	1.65 ± 0.04*	1.54 - 1.76
T15m(sec)	7.54 ± 0.23	7.05 - 8.04	7.40 ± 0.21	6.93 - 7.87	7.36 ± 0.22*	6.88 - 7.84
AE(degrees)	41 ± 1.19	38.41- 43.58	41.92 ± 1.38	38.93 - 44.90	41.21 ± 1.54	37.88 - 44.54
AT(degrees)	25.14 ± 1.61	21.65- 28.62	26.50 ± 1.8	22.61 - 30.38	26.57 ± 2.16	21.89 - 31.24
BT (sec)	0.792 ± 0.019	0.752 -0.834	0.782 ± 0.033	0.711 - 0.854	0.741 ± 0.022*	0.694 - 0.789
VωK(rad/s)	90.99 ± 4.47	81.32-100.66	89.16 ± 4.67$	79.06 - 99.26	107.41 ± 4.89*	96.83-117.99

Significant difference (p<0.05) between Protocol 1 and Protocol 2
$ Significant difference (p<0.05) between Protocol 2 and Protocol 3
* Significant difference (p<0.05) between Protocol 3 and Protocol 1
CI = Confidence Interval
LL = Lower Limit
UL = Upper Limit

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FIGURES LEGENDS

Figure 1. PAP Induction through the Lunge Exercise

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Figure 2. PAP induction through executions on the YoYo Squat flywheel device

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