Journal of Sports Sciences

Eccentric flywheel post-activation potentiation influences swimming start performance kinetics

--Manuscript Draft--

Full Title:	Eccentric flywheel post-activation potentiation influences swimming start performance kinetics
Manuscript Number:	RJSP-2017-1237R3
Article Type:	Original Manuscript
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Response to Reviewers:	Jun 28, 2018 Ref.: Ms. No. RJSP-2017-1237R2 Eccentric flywheel post-activation potentiation influences swimming start performance kinetics Journal of Sports Sciences Dear Author, Reviewers have now commented on your paper. You will see that they are advising that you revise your manuscript. If you are prepared to undertake the work required, I would be pleased to review a revision. For your guidance, reviewers' comments are appended below. If you decide to revise the work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

Eccentric flywheel post-activation potentiation influences swimming start performance kinetics

Running title: PAP on swimming start performance kinetics

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Funding Information:

This project DEP 2014-59707-P "SWIM: Specific Water Innovative Measurements applied to the development of International Swimmers in Short Swimming Events (50 and 100M) has been financed by the Spanish Ministry of Economy, Industry and Competitiveness [Spanish Agency of Research] and

European Regional Development Fund (ERDF). This article is a part of an international thesis belonging to the Program of PhD in Biomedicine (B11.56.1), from the University of Granada, Granada (Spain).

Abstract:

This study aimed to assess the effects of post-activation potentiation in the strength related variables of a kick start. Thirteen competitive swimmers performed three kick starts after a standardized warm up (denoted USUAL) and another after inducing post-activation through five isotonic repetitions on an eccentric flywheel (denoted PAP). A T-test was used to quantify differences between USUAL and PAP warm up. The best trial of each subject achieved by natural conditions (denoted PEAK) was compared with data obtained after PAP. An instrumented starting block with independent triaxial force plates, collected the strength variables related with the impulse at take off. Improvements in the vertical components of force were observed after PAP compared with USUAL, meanwhile no differences were detected on the horizontal components of it. The velocity at take off was higher after PAP compared with the USUAL (4.32 ± 0.88 vs 3.93 ± 0.60 m*s-1; p = 0.02). No differences in force or velocity were detected comparing PAP with PEAK (4.13 ± 0.62 m*s-1, p = 0.11). The PAP warm-up increased vertical force and it was transferred to a higher resultant velocity at take-off. This improvement would equal the best result possible obtained in natural conditions after some trials.

KEY WORDS: Warm-Up; Pre-Activation; YoYo Squat; Force Impulse

Introduction

The swim start is a combination of explosive movements intended to impel the swimmer from the starting block into the water using an optimal steering strategy (Mourao et al., 2015). It should include a fast reaction time, significant jump power, high take-off velocity and low hydrodynamic drag during entry (Beretic, Durovic, Okicic, & Dopsaj, 2013; Honda, Sinclair, Mason, & Pease, 2010). In sprint events, a fast start is fundamental for competitive swimming success (Barlow, Halaki, Stuelcken, Greene, & Sinclair, 2014; Slawson, Conway, Cossor, Chakravorti, & West, 2013), contributing 0.8 to 26.1% of the overall race time depending on the event (Cossor & Mason, 2001). Since the introduction of the Omega starting block in 2011 (OSB11, Corgémont, Switzerland), the so-called *kick* start has been used by almost all competitive swimmers as they can obtain an advantage in the stability of the body due to an increase in horizontal velocity and balance resulting by the reaction forces produced against the rear plate (Honda et al., 2010; Ozeki, Sakurai, Taguchi, & Takise, 2012; Slawson et al., 2013). Adopting a rear weighted body position with the consequence of giving up some reaction time, rather than trying to get off as quick as possible, appears to be the preferred approach taken by elite swimmers to achieve a high impulse at take-off (Barlow et al., 2014; Beretic, Durovic, & Okicic, 2012; Garcia-Hermoso et al., 2013). In that case, the activation of the lower limbs should be maximized (Beretic et al., 2013; Cuenca-Fernandez, Taladriz, et al., 2015).

The post-activation potentiation method has been applied during warm-ups in many competitive sports (Esformes, Cameron, & Bampouras, 2010; Hamada, Sale, MacDougall, & Tarnopolsky, 2000), as a phenomenon wherein a muscular contraction (the conditioning exercise) leads to short-term improvement in the subsequent muscular action (Sale, 2004; Tillin & Bishop, 2009). The use of the term PAP has been suggested to be inappropriate (Cuenca-Fernandez et al., 2017), as it classically refers to enhancement of electrically evoked twitch force. However, it is worth noting that twitch verification is also an indirect surrogate of the effect of actin-myosin phosphorylation in muscle force production (Grange, Vandenboom, Xeni, & Houston, 1998), generating also an increase in the number of cross-bridges formed and consequently a temporary increase in the rate of force development (MacIntosh, 2010). These facts are able to be measured through maximal voluntary contractions, therefore, assuming the limitation that a true PAP effect could be solely verified with the twitches interpolation technique, in the present study it will be measured by its effects on maximal swimming start performance.

The selected load eliciting PAP is frequently obtained some days prior to the test (Cuenca-Fernandez, Lopez-Contreras, & Arellano, 2015; Chiu, Fry, Schilling, Johnson, & Weiss, 2004; Seitz & Haff, 2016). However, on the day of the test subjects may have varied their final performance, either due to skills deterioration/improvement, or due to the fact the load may not have been properly obtained. Previous results reported by Cuenca-Fernandez, Lopez-Contreras, et al. (2015) showed that it would be interesting to use inertial systems to solve this issue. Improvements in kinematic variables of a swim start were obtained as a consequence of adding repetitions on an eccentric flywheel straight away after the swimming warm up. The authors concluded that as the resistance was proportional to the force applied, it generated high lower limb activation due to the high requirements of power and strength in the concentric and eccentric phases from the first repetition of each set (Chiu & Salem, 2006). Hence, maximal muscle stimulation can be achieved regardless of a subject's condition on the day of the test, with possible great benefits on the subsequent kick start performance.

Although applying this specific pre-activation protocol in competition seems unfeasible (a specialist piece of equipment is required while athletes are waiting in the call-up room), the influence of PAP on swimming start kinematic variables have showed optimistic outcomes, at least in experimental conditions (Cuenca-Fernandez, Lopez-Contreras, et al., 2015). Therefore, the effects of the propelling forces acting on the block should be better understood. In fact, by using a swimming instrumented block with independent triaxial force plates (de Jesus, Sanders, et al., 2016; Mourão et al., 2016), it is possible to obtain the strength variables related with the impulse and explosiveness of each limb at take-off, and also, identifying the performance variations magnitude associated with the application of PAP to verify if a swimming start could be improved after using it. Therefore, the aim of the current study was to assess the effects of a PAP conditioning exercise based on eccentric flywheel maximal repetitions in the strength related variables of a swim start.

Methods

Approach to the problem:

A T-test design was used to compare swimmers force & impulse values developed by the lower limbs in an instrumented starting block equipped with a back plate (Figure 1); (de Jesus, Sanders, et al., 2016; Mourão et al., 2016). Two conditions were randomly tested; the first condition (denoted USUAL), was performed after a standard warm up and it was obtained by averaging three swimming starts performed with one leg positioned on the back plate, that is to say, kick start. The second condition (denoted PAP), consisted in the same warm up performed in the USUAL condition and followed by PAP inducement through five repetitions on an eccentric flywheel. The PAP conditioning exercise focused on lower limb muscles was performed on an inertial flywheel nHANCE™ Squat Ultimate (YoYo™ Technology AB, Stockholm, Sweden), allowing the realization of a motion very similar to the real starting action (Figure 2).

(Insert Figure 1 near here)

(Insert Figure 2 near here)

The trial expressing the highest value of the resultant velocity of every swimmer was identified and all the related variables were extracted from the three kick starts performed in the USUAL condition, in order to compound a new category.

This *best trial* (denoted PEAK), gathered the best outcomes obtained from each subject across standard trials (regardless of the trial in which they were performed), and was compared with the PAP condition with the purpose of detecting if a start using PAP may be faster than the fastest/quickest start that a swimmer could do without PAP. To the author's knowledge, the resultant velocity expresses effectively reliable information about the performance on a swimming start for this study in particular, since it was derived as the integral over time of the horizontal and vertical forces acting against the block.

Subjects:

Thirteen competitive swimmers provided written informed consent and volunteered to take part in this study. The male (n=11) and female (n=2) main physical and competitive background characteristics are (mean ± SD): 18.95 ± 1.63 vs 19.02 ± 0.78 years old, 76.61 ± 9.12 vs 59.43 ± 8.23 kg of body mass, 1.81 ± 0.03 vs 1.62 ± 0.05 m of height and ≤ five years of national level competitive participation. Before the testing started, the swimmers received information about the experimental procedures and possible risks associated. Swimmers under the age of 18 were asked to provide parental consent. All the subjects were asked to avoid any physical exertion prior to testing and refrain from alcohol and caffeine for the previous 24 h.

Variables Measured:

The variables measured in the current study are described in Table 1.

(Please insert Table 1 near here)

Experimental procedures:

All procedures were performed in accordance with the requirements of the Declaration of Helsinki and were approved by the local ethics committee. In a 25-m indoor pool (28.2 and 29.1ºC of water and air temperatures), participants were randomly assigned into two conditions. The first condition replicated the swimming warm up previously applied by Cuenca-Fernandez, Lopez-Contreras, et al. (2015) for the same experimental testing. It consisted of a conventional warm up to 400 m at front crawl, moderate intensity and two starts from the wall. Then, they performed a dynamic stretching protocol, consisting of specific exercises for jump performance, with each performed 10 times with the entire set repeated twice (one set per min). After six min of rest, swimmers performed three kick starts with 6 min intervals in-between. On the study of Cuenca-Fernandez, Lopez-Contreras, et al. (2015), eight minutes of rest were given between PAP conditioning exercise and test. In the present study, though, only six minutes of rest were given between PAP and swim start testing, as some literature has shown as acceptable for dissipating fatigue while activation still exists (Hancock, Sparks, & Kullman, 2014; Maloney, Turner, & Miller, 2014).

In the second condition, warm up followed by repetitions in eccentric flywheel were replicated according to Cuenca-Fernandez, Lopez-Contreras, et al. (2015). Briefly, characteristics of the device used are fully described in the references (Tesch, Ekberg, Lindquist, & Trieschmann, 2004). The initial position consisted on the same position that was performed by swimmers on the starting block, with the same front/behind placing of lower limbs (Figure 2). Once the device harness was fitted to the swimmers' upper body and tensed into the device, they performed five maximum intensity repetitions. The reason for the election of five repetitions was that the first repetition serves to charge the flywheel spin. During the entire exercise, a study collaborator monitored the initial position and provided swimmers with the device harnesses. Subsequently, each swimmer performed a swim start after six min of rest.

Start trials were performed on a dynamometric instrumented starting block (complying with FINA rules; FR 2.7), that included five triaxial and independent above water force plates, two for hands and three for feet force measurements (de Jesus, de Jesus, et al., 2016; Mourão et al., 2016), with a sensitivity of 0.5 N, error < 5%, displaying accurate and reliable measurements. All strain outputs were converted to digital data through an analogue to digital converter via strain gauge input models NI 9237 connected to a chassis CompactDAQ USB-9172 and to an Ethernet-9188 (National Instruments Corporation, USA). Data processing software was created in Lab View 2013 (SP1, National Instruments Corp., USA) to acquire, plot and save the force plates data in real time (2000 Hz sampling rate).

The start signal complying with the FINA rules (SW 2.4 and 6.1) was produced through an official device (OMEGA StartTime IV acoustic start, Swiss Timing Ltd., Switzerland) and delivered simultaneously a pulse in the direction of the force plates with convenient signal conditioning. A processing custom-designed routine computational environment was used to: i) convert strain readings (με) into force values (N); ii) force offset removal; iii) filter force exerted on feet (4^{th} order zero-phase digital Butterworth low-pass filter with a 10Hz cut-off frequency); and iv) sum lower limb force data and normalize each force curve to individual swimmer's weight (N/N) and time in vector to maximum value (s/s) (de Jesus, de Jesus, et al., 2016).

Statistical analysis:

Descriptive statistics were obtained and the data were expressed as mean ± SD and respective effect sizes (SPSS Version 21.0, IBM, Chicago, IL, USA). After Saphiro-Wilk testing for normality distribution, T-test ANOVA was carried out to determine differences concerning the USUAL (average across trials 1-3) to the PAP condition. To detect differences between variables, significance was accepted at the alpha ≤ 0.05 level. The same analysis was applied to compare results from PAP protocol with results from the PEAK condition. The criterion for selecting that particular trial and all the variables associated to such specific achievement was the highest value expressed for resultant velocity.

Results:

Mean, SD, *p* – values and effect sizes for all tested swimming starts related variables are presented in Table 2 for the three conditions. The values variations achieved along the tests depending on the swim start or condition are shown for each trial in Figures 3 and 4. No differences were found for reaction time, movement time or block time in any of the comparisons between USUAL and PAP ($p > 0.1$), nor when the PEAK condition was considered on the analysis.

(Please insert table 2 near here)

The average horizontal and vertical force registered on the block did not vary on any of the conditions exerted and no variations were observed when compared after PAP condition with the PEAK (Table 2). Peak horizontal force values not shown differences between the USUAL and PAP condition. Nonetheless, the values after PAP condition were lower than in the PEAK (PAP trial: 624.39 ± 58.60 N vs. PEAK trial: 700.58 ± 30.99 N) (Figure 3, Graph A). Peak vertical force values were higher after PAP condition than obtained after the USUAL, but no differences were found when performance after PAP condition was compared with the PEAK (Table 2). Subjects did not vary horizontal impulse exerted on the plates. When analyzing vertical impulse values, differences were shown comparing the USUAL and the PAP trial ($p = 0.04$) (Table 2). A trend close to show significance was detected comparing PAP and the PEAK ($p = 0.059$), as subjects achieved the highest values of the test after experimental condition (Figure 3, Graph B). Resultant impulse values did not show differences between any of the three conditions.

The values of horizontal velocity kept stable along the experiments (Figure 4, Graph A). Differences in vertical velocity were observed between the USUAL and PAP trial ($p = 0.05$). Analysis was close to reveal differences comparing vertical velocity in the PAP trial with the PEAK ($p = 0.058$). Resultant velocity values were higher for the PAP trial in comparison to the USUAL ($p = 0.028$), but no comparing with the PEAK (Table 2).

(Please Insert Figure 3 near here)

(Please Insert Figure 4 near here)

Values obtained in horizontal acceleration and power (average and peak) did not show differences in any condition. Conversely, differences were found between USUAL and PAP in vertical acceleration (average) and vertical power (average) (Table 2). Results for vertical acceleration and power (peak) at PAP trial achieved the highest value of the test, but the differences only were found compared with the USUAL (Table 2). Values for resultant power (average and peak) did not show statistical differences in any of three conditions (Figure 4, Graphs B & C).

The rate of force development expressed differences between USUAL and PAP trial ($p = 0.04$). Values after PAP were the highest registered in the test. However, no differences were found when compared with the values from the PEAK (Table 2). No differences were found for horizontal force/impulse and vertical force/impulse from the rear leg in any of the comparisons made between USUAL and PAP trial, and also comparing the PAP trial with the PEAK ($p > 0.1$). Analyzing horizontal force/impulse and vertical force/impulse from the front leg, no differences were revealed between USUAL and PAP trial ($p > 0.1$), nor comparing with the PEAK (Figure 3, Graphs C & D).

Discussion:

The aim of the current study was to assess the effects of a PAP conditioning exercise based on eccentric flywheel maximal repetitions on the strength related variables of a swim start. Our results suggest that swimming start performance can be slightly improved after five maximal repetitions conducted on an eccentric flywheel, as a result of enhancements in the vertical components of the force of the lower limbs' action. The PAP warm-up produced increments in the vertical propelling forces and it was transferred to a higher resultant velocity at take-off. However, given the small size of the differences comparing the results obtained after PAP protocol with those collected from the best trial (PEAK), and the lack of effects in all the variables related with the horizontal component of force production, these improvements after PAP would only equal the best result possible achieved in natural conditions.

Swim starts are explosive and organised movements intended to propel the swimmer from the starting block as quick and as far as possible (Mourao et al., 2015). In the current study, no variations regarding temporal variables were detected in any of the conditions. This was a positive point as, although no comparison between different starting techniques was made, swimmers showed high consistency between trials even when some small variations occurred in performance. In short events, hundredths of seconds are key points of success and swimmers need to train the ability of reacting fast after the starting signal. Therefore, little or no benefit may be obtained after an improved take-off velocity following a PAP warm-up if the time spent on the block is too large (Seifert et al., 2010).

According to some authors, the block phase influences performance in the subsequent components of the start and, therefore, it is important for swimmers to optimize it (Mason, Alcock, & Fowlie, 2007). Some studies have shown the relationship between lower body muscle force and start performance (Beretic et al., 2013; Cuenca-Fernandez, Taladriz, et al., 2015; Garcia-Ramos et al., 2016; Slawson et al., 2013; West, Owen, Cunningham, Cook, & Kilduff, 2011) and the results suggest that swimmers who possess greater maximum force and specific rate of force development at absolute and relative levels, tend to achieve faster velocities at take-off and to swim faster on initial meters of a swim start performance (Beretic et al., 2013; West et al., 2011). Swimmers experienced a change in performance by generating more vertical force and velocity and such effects contributed to transfer this improvement to the total resultant movement. As a consequence, resultant velocity took part of such vector distribution and subjects obtained an improvement in their performance for leaving the block at a higher resultant speed (Figure 4, Graph A). Unfortunately, kinematic variables were not added into our results, therefore we could not certify that swimmers entered into the water with a long dive distance or a correct entry angle as a consequence of such improved speed.

In the present study, no improvements were observed after PAP for any of the horizontal variables derived from the force plates: ground reaction forces, acceleration and impulse (average and peak). Meanwhile, vertical forces improved as a result of the PAP stimulation and this was transferred to all the dependent variables of vertical force (average & peak). Considering that the improvement in performance seen after PAP is very specific to the task used as a condition of warm-up (Seitz & Haff, 2016), it is conceivable to argue that the lack of improvement in the horizontal direction might be a consequence of a PAP conditioning exercise with a predominance of vertical movement (Figure 2). These results are in conflict with the ones obtained by Kilduff et al. (2011). The traditional swimming warm up was substituted by an experimental protocol based on three maximal back squat repetitions at 87% of 1RM (Kilduff et al., 2011). Swimmers were then tested in a swimming start by using a force plate placed on the swimming block and the outcomes revealed that both peak horizontal and vertical forces exerted on the block were indeed augmented after such experimental warm up. Although both studies purported mimicked the kinesiologic-lower limb movement of a swimming start through vertical-based movements, the results obtained on the present study seemed to show some constraints directly emanated from the conditioning exercise, possibly due to the asymmetric feet emplacement while executing the exercise (Chiu & Salem, 2006).

Nonetheless, the results of Kilduff et al. (2011) were obtained in a *track* ventral start by using a single force plate mounted on the block. Meanwhile, in the current study, a *kick* start was tested on an experimental block start composed of multiple force plates (Figure 1). Fact contributing to a different interpretation of the results (de Jesus, Sanders, et al., 2016). Swimming starts performed in the OMEGA starting block allow the swimmer to obtain an advantage in terms of stability and force production (Honda et al., 2010; Ozeki et al., 2012; Slawson et al., 2013). When horizontal force and movement are guaranteed by the movement done by the rear foot on the back plate, the front lower extremity may assume a higher implication to provide a vertical impulse on the system. This fact was suggested by the vertical force and impulse values obtained on the front leg in this study. Although those results were only trends, they are in agreement with the results obtained in a previous research (Takeda, Sakai, Takagi, Okuno, & Tsubakimoto, 2017). Taking into account the characteristics of the conditioning exercise, more force is produced by the front leg given the asymmetric feet placement on the flywheel device and the eccentric overload while breaking the flywheel (Chiu & Salem, 2006; Norrbrand, Pozzo, & Tesch, 2010). The subsequent impulse action of each repetition could have supposed thus favourable adaptations to the first stages of a swimming start impulse, where an overload on the front leg provided by the pull action of the hands compressing the body against the block (Takeda et al., 2017), is solved with a subsequent force production.

Regarding the variables related to the explosiveness of the take-off, only the vertical values of power (average & peak) and acceleration (average) were higher after PAP. However, no differences were found in the horizontal and resultant values of the aforementioned variables (Table 2; Figure 4, Graphs B & C). The results are nonetheless worthy of review. One reason behind these outcomes is the aforementioned relation between the vertical force measures found and the transference to all the dependent variables of it, such as acceleration and power. On the other hand, another possible reason could be the relationship between the horizontal force exerted on the block and the speed of the movements (Sarabia, 2015). Power is the product of force and speed. According to some authors (Baker, 2003; Brandenburg, 2005; DeRenne, 2010) the speed of the movements could have an important role in the fast muscle fibber unit’s activation, thus high intensity stimulus (100%) performed at slow speed could have an attenuating effect of the neural output, reducing the possibility of favourable adaptations in subsequent power exercises. Repetitions on eccentric flywheel definitively caused a transitory improvement in the vertical force applied to the block because a quick motion was predominantly performed down- and upwards. However, an adaptation on the flywheel set up, allowing swimmers to adopt a more horizontal position, should be considered in future studies to also ensure fast movements in the horizontal plane (Norrbrand et al., 2010; Thomas, Toward, West, Howatson, & Goodall, 2017).

As the rate of force development is an expression of force production in a short time, the refinement of the values obtained in this variable could support the idea that explosiveness could be improved after PAP protocols previously proposed by some authors (Beretic et al., 2013; West et al., 2011). Results showed in this study partially supported such idea, as the differences were only found by comparing PAP values with those obtained after the USUAL condition, but no differences were found when the values of rate/ the rate values of force development after PAP were compared with the PEAK. Possibly, the effects of actin-myosin phosphorilation increases peak forces after PAP, producing the improvements found in force components in that condition (Grange et al., 1998; MacIntosh, 2010). However, a possible limitation of this study may reside on the fact that the effects of PAP have also been reported on the neuromuscular system due to an intensification of the muscle fiber recruitment when muscle contractions are performed at high speed (Hamada et al., 2000; Sale, 2004). Considering that in the USUAL condition three kick starts were performed in a row, the possible effects of the motor-neuron's excitation elicited by the maximal voluntary take-off extension movement might be the reason why that optimal performance was also achieved in natural conditions.

In conclusion, by applying a conditioning exercise based on repetitions on eccentric flywheel, some improvements in performance (associated with PAP effect) can be indeed obtained, as it caused a moderated influence on swimming start performance. This improvement would come due to the improvement obtained in the vertical axes of force production. It suggests that slight increments in the vertical components of force/impulse, rather than in the horizontal vectors of it, might be crucial for obtaining improvements in a swimming start performance. However, the improvement after PAP, would only equal the best possible result achieved in natural conditions. As most of the swimmers were already elite in their performance, it could be possible that fewer increases were seen with PAP because of the high level of performance of the swimmers. Future studies should test if adding a control group of non-elite swimmers would show greater results after PAP.

Conclusion:

The relevance of our study is the application of a device designed for training as a tool to induce post-activation potentiation with the purpose to improve performance of swimmers on a swim kick start. The effect on the velocity at take-off or the increase in vertical forces exerted on the block leads us to consider the use of this device prior to competition in short events. However, given the infeasibility of using it six minutes prior to getting on the block or while waiting in the call-up room, lead us to recommend it preferably as an interesting training tool for coaches, as an extension movement can be effectively performed with lower limbs. Therefore, the possible modifications induced on technique as well as the adaptations of this kind of method to competitive constraints should be resolved in the future.

Disclosure statement:

The authors have no conflicts of interest to report.

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Figure legends and tables:

- **Figure 1.** Instrumented swimming starting block, replicating OMEGA OSB 12, with its five independent extensiometric triaxial force plates (P).
- **Figure 2.** Initial and final positions of the conditioning exercise on the nHANCE™ Squat Ultimate (left and right panels, respectively).
- **Figure 3.** Variation of ground reaction forces variables depending on the swimming start and/or the condition performed. (AvFH, AvFV, PeFH and PeFV: Horizontal/vertical force average or peak; ImpH, ImpV and ImpRES: Horizontal, vertical and resultant impulse;; Ihands: Hands vertical impulse; ForceREAR_HOR, ForceREAR_VER, ForceFRONT_HOR and ForceFRONT_VER: Horizontal/vertical force rear or front leg; ImpHOR_REAR, ImpVER_REAR, ImpHOR_FRONT and ImpVER_FRONT: Horizontal/vertical impulse rear or front leg; (USUAL: Swimming start average values across trials 1-3; PAP: swimming start after post-activation potentiation; PEAK: The best trial of each subject achieved by natural conditions on the standard trials).
- **Figure 4.** Variation of velocity, acceleration and power variables depending on the swimming start and/or the condition performed (VelH, VelV and VelRES: horizontal, vertical and resultant velocities; AvAccelHOR, AvAccelVER, PeAccelHOR and PeAccelVER: horizontal/vertical and average or peak acceleration. AvPOWER_HOR, AvPOWER_VER, PePOWE_HOR, PePOWER_VER, ResPOWER_Av and ResPOWER_Pe: horizontal/vertical, average or peak and resultant power; (USUAL: Swimming start average values across trials 1-3; PAP: swimming start after post-activation performance enhancement; PEAK: The best trial of each subject achieved by natural conditions on the standard trials) (N=13).

- **Table 1.** Description and formula of the variables measured in the swimming instrumented start block.

- **Table 2.** Mean, SD, p – value and effect sizes for the strength variables obtained from the experimental swimming start block in the three studied conditions (n=13).

Table 1. Description and formula of the variables measured in the instrumented swimming start block.

NAME	DESCRIPTION	FORMULA
Reaction Time	Time between the starting signal (trigger) and time in which ground reaction forces (GRF) change from body mass (m_b).	$RT = t_{(GRF \neq m_b)} - t_{(Trigger)}$
Movement Time	Time between the reaction time and the end of the push-off (GRF dropped to 0).	$MT = t_{(GRF=0)} - t_{(GRF \neq m_b)}$
Block Time	The sum of reaction time and movement time.	$BT = RT + MT$
Average Force	Calculated as horizontal/vertical impulse divided by movement phase time.	$AvF = \frac{Impulse}{MT}$
Peak Force	The greatest horizontal/vertical force reached during the movement phase.	$PeF = Max\ (\Delta F)$
Horizontal Force Impulse	Where *s* stands for the instant of the force change, *e* for the end of push-off and *Fh* stands for horizontal forces; *Δt* was 1/2000 (frequency of data acquisition: 2000 Hz).	$I_H = \sum_{s}^{e} F_h \Delta t$
Vertical Force Impulse	Where m_b stands for the body mass; *Fv* for the sum of the vertical forces exerted by the rear and the front leg (forces while waiting for the start signal were extracted).	$I_V = \sum_{s}^{e} (F_v - m_b g)\Delta t$
Resultant Impulse	Calculated from component's impulses (horizontal & vertical) using Pythagorean Theorem.	$I_{Res} = \sqrt{{I_H}^2 + {I_V}^2}$
Velocity *Horizontal/Vertical*	Calculated from corresponding force impulse (Horizontal or vertical) at take-off, divided by body mass (m_b).	$Vel = \frac{I}{m_b}$
Resultant Velocity	Calculated as resultant impulse at take-off divided by body mass (m_b).	$Res_v = \frac{I_R}{m_b}$
Average Acceleration	Calculated as average horizontal/vertical force divided by body mass (m_b).	$AvAccel = AvF\ /\ m_b$
Peak Acceleration	Calculated as peak horizontal/vertical force divided by body mass (m_b).	$PeAccel = PeF\ /\ m_b$
Power *(Average/Peak)*	Calculated as (average or peak) horizontal/vertical force multiplied by horizontal/vertical velocity.	$Av_{Power} = AvF \cdot Velocity$ $Pe_{Power} = PeF \cdot Velocity$
Resultant Power	Calculated from component's Average/Peak power using Pythagorean Theorem.	$Res_{Power} = \sqrt{{Pw_H}^2 + {Pw_V}^2}$
Rate of Force Development	Obtaining the horizontal/vertical component of Rate of Force Development as peak horizontal/vertical force divided by time to reach it; and applying the Pythagorean Theorem.	$RFD = \sqrt{{RFD_h}^2 + {RFD_v}^2}$
Force Rear/Front Leg	Calculated as horizontal/vertical impulse of the rear or front leg acquired with the rear/front force plate, divided by movement phase time of the rear/front leg.	$Force = \frac{I_{Rear/Front}}{MT}$
Horizontal Impulse *(Rear/Front Leg)*	Where *s* stands for the instant of the force change, *e* for the end of push-off and *Fh* represented the horizontal forces exerted by the rear/front leg; *Δt* was 1/2000 (Hz).	$I_{Hor} = \sum_{s}^{e} F_h \cdot \Delta t$
Vertical Impulse *(Rear/Front Leg)*	Where *Fv* stands for the vertical force registered in the rear/front plate; m_b stands for the body mass registered in the rear/front leg and *Δt* for 1/2000 (Hz).	$I_{Ver} = \sum_{s}^{e} (F_v - m_b g)\ \Delta t$

Table 2. Mean, SD, p – value and effect sizes for the strength variables obtained from the experimental swimming start block in the three studied conditions (n=13).

VARIABLE	USUAL	PAP	PEAK	P value	Effect Size (95% CI)	P value	Effect Size (95% CI)
AvF_H (N)	378.83 ± 57.43	378.04 ± 77.67	384.07 ± 83.88	0.96	-0.01 (-1.09, 1.07)	0.78	0.07 (-1.01, 1.16)
AvF_V (N)	27.18 ± 144.14	58.28 ± 195.27	30.38 ± 183.98	0.42	0.18 (-0.90, 1.27)	0.52	-0.14 (-1.23, 0.94)
PeF_H (N)	684.38 ± 155.81	624.39 ± 211.28†	700.58 ± 151.75	0.14	-0.32 (-1.41, 0.77)	0.05	-0.41 (-1.51, 0.68)
PeF_V (N)	509.55 ± 105.26	551.79 ± 106.43*	542.08 ± 122.94	0.05	-0.39 (-1.49, 0.69)	0.78	-0.08 (-1.17, 1.00)
Imp_H (N·s)	234.02 ± 28.20	234.20 ± 27.18	242.18 ± 34.47	0.97	0.00 (-1.08, 1.09)	0.29	0.25 (-0.83, 1.34)
Imp_V (N·s)	18.25 ± 29.54	41.35 ± 35.91*	22.68 ± 37.39	0.04	0.70 (-0.41, 1.82)	0.06	-0.49 (-0.59, 1.61)
Imp_{RES} (N·s)	251.27 ± 34.41	267.09 ± 38.17	274.06 ± 45.84	0.09	0.43 (-0.66, 1.53)	0.46	0.16 (-0.92, 1.25)
Vel_H ($m·s^{-1}$)	3.64 ± 0.50	3.66 ± 0.45	3.78 ± 0.51	0.80	0.04 (-1.04, 1.12)	0.29	0.25 (-0.84, 1.34)
Vel_V ($m·s^{-1}$)	0.29 ± 1.43	0.78 ± 1.86*	0.28 ± 1.89	0.05	0.30 (-0.79, 1.38)	0.06	-0.25 (-1.34, 0.83)
Vel_{RES} ($m·s^{-1}$)	3.93 ± 0.60	4.32 ± 0.88*	4.13 ± 0.62	0.02	0.51 (-0.58, 1.62)	0.11	-0.25 (-1.34, 0.84)
$AvAccel_{HOR}$ ($m·s^{-2}$)	5.86 ± 0.86	5.91 ± 1.21	5.95 ± 0.90	0.94	0.04 (-1.04, 1.13)	0.89	0.03 (-1.05, 1.12)
$AvAccel_{VER}$ ($m·s^{-2}$)	0.63 ± 2.28	1.38 ± 2.99*	0.72 ± 3.11	0.04	0.35 (-0.81, 1.37)	0.12	-0.21 (-1.30, 0.87)
Av_{POWER_HOR} (W)	1393.91 ± 293.87	1398.49 ± 386.56	1455.17 ± 354.92	0.96	0.01 (-1.07, 1.10)	0.61	0.15 (-0.93, 1.24)
Av_{POWER_VER} (W)	206.08 ± 247.92	402.03 ± 444.20*	280.82 ± 419.23	0.05	0.54 (-0.56, 1.65)	0.16	-0.28 (-1.37, 0.81)
Pe_{POWER_HOR}(W)	2517.17 ± 626.73	2529.06 ± 589.86	2667.57 ± 623.06	0.96	0.02 (-1.60, 1.10)	0.35	0.22 (-0.86, 1.31)
Pe_{POWER_VER} (W)	530.49 ± 924.76	926.38 ± 1425.36*	615.70 ± 1247.53	0.04	0.33 (-0.76, 1.42)	0.12	-0.23 (-1.32, 0.85)
RFD (N/s)	3261.16 ± 2029.73	3780.39 ± 2675.87*	3553.32 ± 2394.49	0.04	0.21 (-0.87, 1.30)	0.36	-0.08 (-1.17, 0.99)

* Differences ($p < 0.05$) in performance compared with USUAL.

† Differences ($p < 0.05$) in performance compared with PEAK.

Figure

Figure 1. Instrumented swimming starting block, replicating OMEGA OSB 12, with its five independent extensiometric triaxial force plates (P).

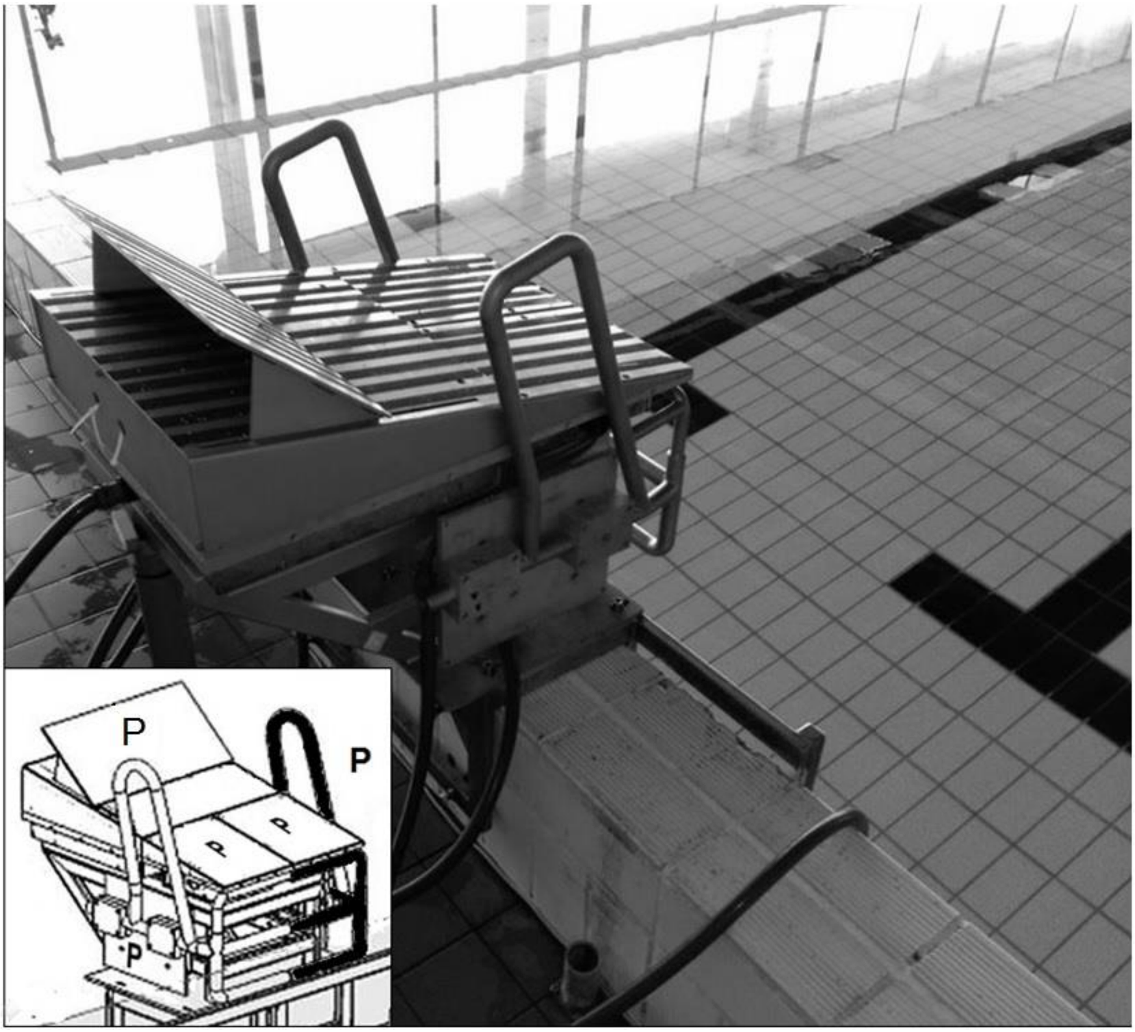
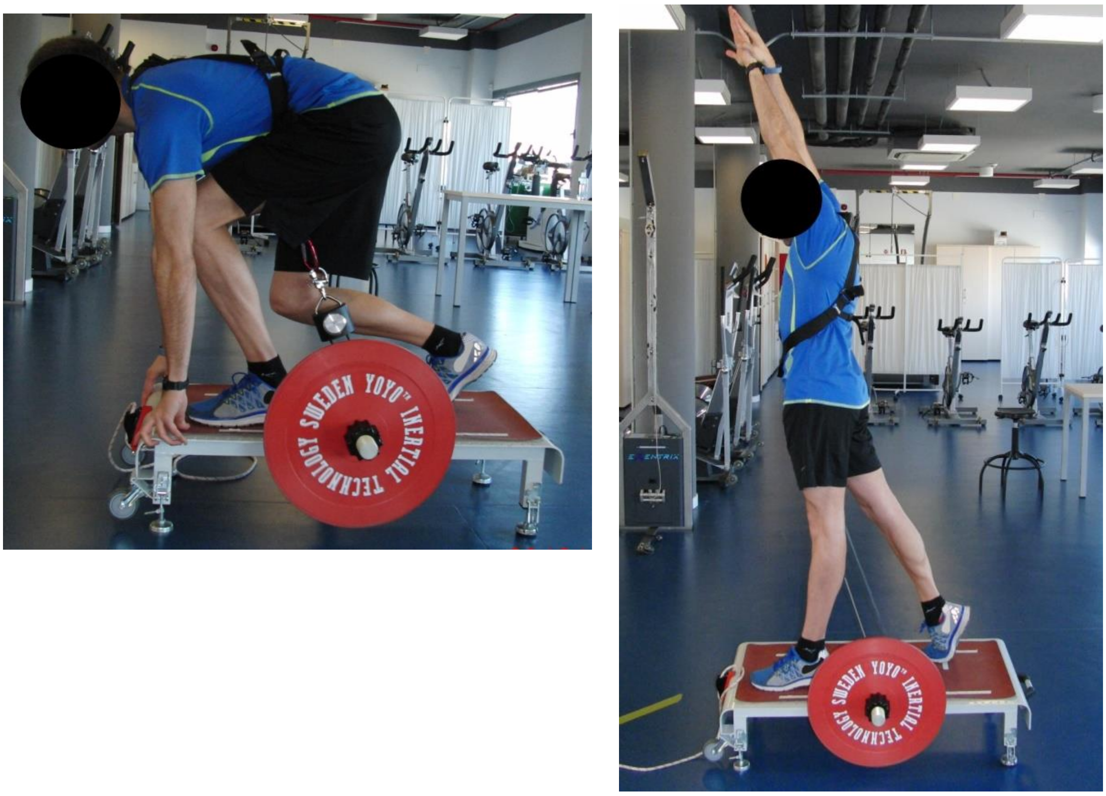


Figure 2. Initial and final positions of the conditioning exercise on the nHANCE™ Squat Ultimate simulating a swimming kick start (left and right panels, respectively).



Figure

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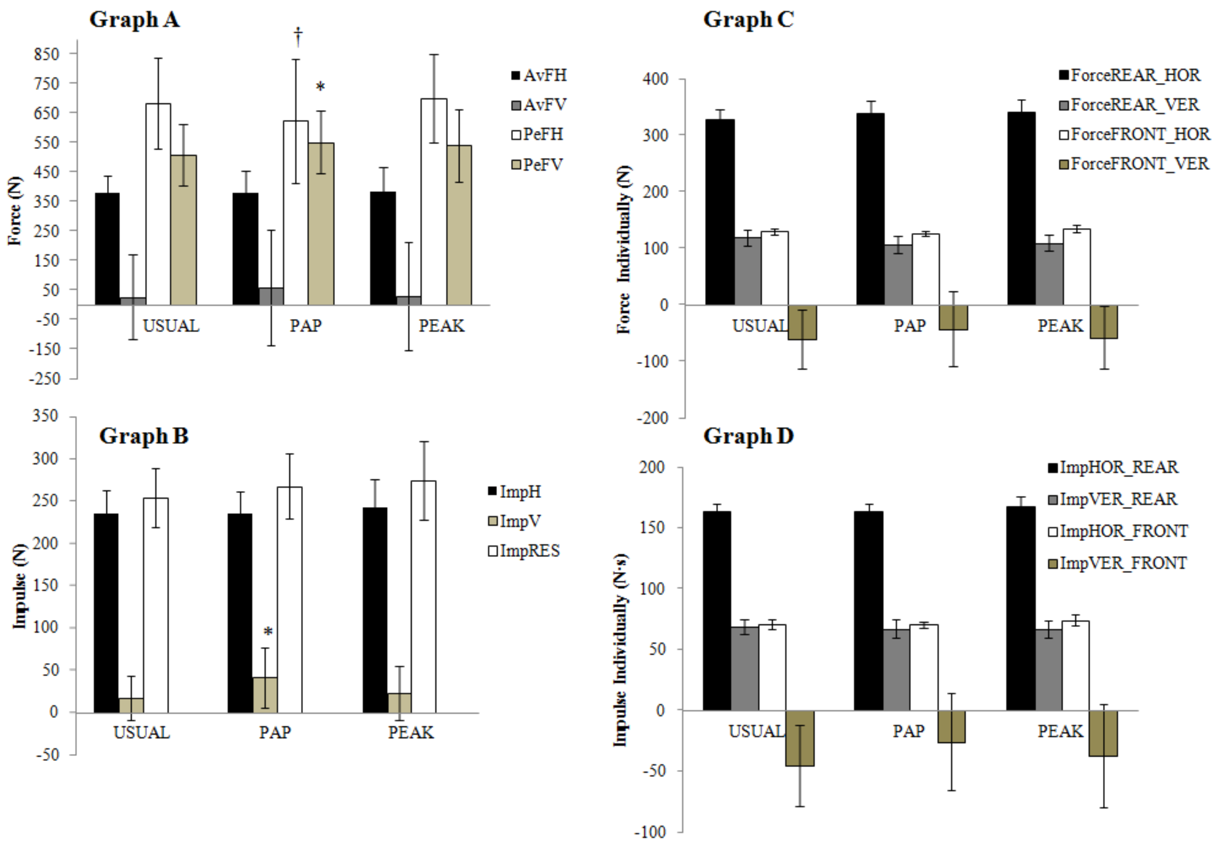

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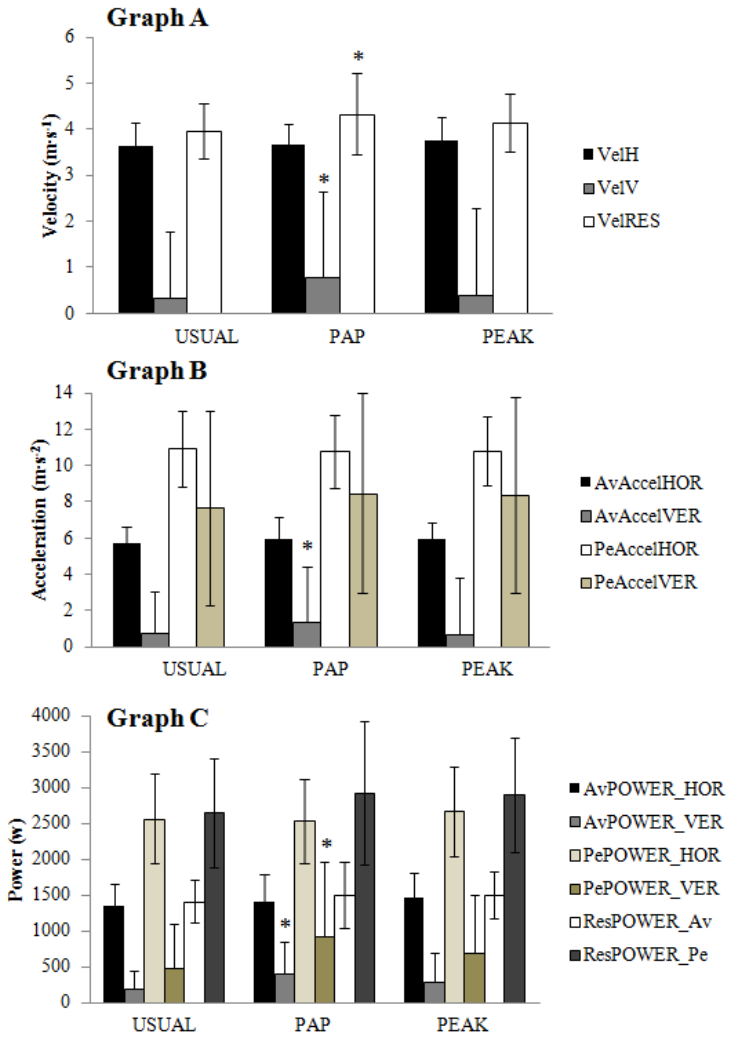

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