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Post-Activation Potentiation on Squat Jump Following Two Different Protocols: Traditional vs. Inertial Flywheel

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Post-activation potentiation (PAP) has been defined as a major enhancement of muscular performance following a preload stimulus. The eccentric actions seem to cause a potentiating effect on subsequent explosive exercises. The aim of this study was to determine whether a protocol of squat exercise using an inertial flywheel could have a potentiating effect on jump performance. Sixteen physically active volunteers participated in the study (age: 21.8 ± 2.7 years; body mass index: 23.6 ± 3). All participants completed two different protocols on separate days: a Traditional Protocol (using a half squat with a guided barbell) and an Inertial Flywheel Protocol (using a half squat with an inertial flywheel). Both protocols were similar and consisted of 3 x 6 reps at the load that maximized power, with a 3-minute rest interval between sets. The squat jump (SJ) was measured by a contact platform at baseline, and four, eight and twelve minutes after the PAP stimulus. A two-way ANOVA with repeated measures was performed to analyze significant differences over time. There were significant increases of SJ height (p = 0.004, d = 0.665), velocity (p = 0.003, d = 0.688) and power (p = 0.004, d = 0.682) from baseline after the inertial flywheel protocol. A significant interaction effect (time x protocol) was observed, showing that the inertial flywheel protocol had a potentiating effect on the jump performance compared to the traditional protocol, more specifically at 4 and 8 minutes after the PAP stimulus. In conclusion, the inertial flywheel protocol showed a potentiating effect on the squat jump performance, thus this pre-conditioning activity could be useful during the warm-up before the competition.

Key words: *muscle pre-activation, eccentric overload, conical pulley, half squat, explosive movement.*

Introduction

Post-activation potentiation (PAP) has been defined as an acute enhancement of muscular performance following a preload stimulus with maximal or submaximal muscle actions (Gołaś et al., 2017; Hughes et al., 2016). Different physiological mechanisms have been proposed to explain the PAP. On the one hand, the phosphorylation of myosin regulatory light chains, what is related to increased rates of force development and peak isometric force (Baudry and Duchateau, 2007). On the other hand, previous muscle contraction could raise the excitability of α–motoneurons, what may raise the

fast-twitch fiber contribution (Koziris, 2012). In addition to this, some authors have even suggested a shortening of the pennation angle that may positively influence the force transmission to the tendon (Tillin and Bishop, 2009).

This mechanism of potentiation is used during the warm-up to improve competitive performance, especially for high-power movements as jumps, throws or sprints (Gołaś et al., 2016). The balance between PAP and fatigue will determine the effect on the subsequent exercise, improving muscle performance if potentiation is greater than fatigue (Andrews et

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al., 2016). According to the scientific literature, PAP can be influenced by several factors, such as the type of exercise during the previous stimulus (intensity, volume, number of sets, range of motion and specificity of movement), the recovery period following the stimulus, the type of subsequent activity, and the training status of participants (Seitz and Haff, 2016; Tillin and Bishop, 2009).

However, to the best of our knowledge there is no research regarding the potentiation effect of an inertial flywheel protocol on the squat jump performance. Nonetheless, a previous study found that performance of 4 repetitions of lunge exercise on the YoYo flywheel device (YoYo Technology AB, Stockholm, Sweden) during the warm-up improved swimming start performance (Cuenca-Fernández et al., 2015). During the concentric phase of the movement, the flywheel rotates and the device stores kinematic energy. After that, the athlete must resist the inertial force of the flywheel and brake during the eccentric phase of the movement. This braking action involves an eccentric overload that causes a maximal voluntary contraction (Norrbrand et al., 2010). Eccentric contractions are characterized by higher solicitation of type II fibers and greater cortical activity (Maroto-Izquierdo et al., 2017), attaining a greater power and muscle activation compared with free weight resistance exercises (Norrbrand et al., 2010). In addition, eccentric actions activate elastic components in the muscle by the stretch-shortening cycle, increasing the production of force in subsequent actions (Hof, 2003). Several studies have concluded that the eccentric contraction prior to the explosive exercises stimulated the mechanism of PAP (Gołaś et al., 2016, 2017a; Hughes et al., 2016). On the other hand, the flywheel technology allows to individualize training by identifying the inertial load where peak power occurs for each individual, so all repetitions can be performed with maximal voluntary effort and maximal possible speed during exercise (de Hoyo et al., 2015; Martinez-Aranda and Fernandez-Gonzalo, 2016). Previous studies stated that PAP obtained with ballistic exercises was greater to that elicited with nonballistic exercises (Seitz and Haff, 2016; Suchomel et al., 2016). Likewise, a pre-conditioning activity based on plyometric exercises (involving activation of the stretch-

shortening cycle) seems to induce a PAP effect slightly higher than moderate or high intensity concentric workouts (Seitz and Haff, 2016).

Based on this background, it was considered relevant to evaluate the potentiation effect of an inertial flywheel protocol. Thus, the purposes of this study were to determine the PAP effect of an inertial flywheel protocol on squat jump performance, and to compare the potentiation effect of this protocol with the effect caused by a traditional protocol performed with a guided barbell machine.

Methods

Participants

Sixteen physically active students (9 males and 7 females) volunteered for this study (age: 21.8 ± 2.7 years; body mass: 70.4 ± 12.7 kg; body height 172.2 ± 9.8 cm; body mass index: 23.6 ± 3.0; % fat mass: 20.1 ± 7.5). They were identified as highly or moderately active individuals according to the International Questionnaire of Physical Activity (Craig et al., 2003). All participants were free of any musculoskeletal injuries in the lower limbs and they were able to perform several squat repetitions with heavy loads (evaluated during a practice session). The subjects attended the laboratory at the same time of the day (± 2 h), without having performed strenuous lower limbs exercises in the preceding 48 h, and without having ingested any type of stimulating substance or alcohol in the 12 hours prior to the session. All testing and training protocols were explained and written informed consent was obtained from all participants before starting the study. The research was approved by the University Ethics Committee and met the requirements of the Declaration of Helsinki.

Design and Procedures

A randomized and counterbalanced crossover design was used to determine the PAP effect on the subsequent squat jump (SJ) of two different protocols: a Traditional Protocol (TP) vs an Inertial Flywheel Protocol (IFP). During the first week, two practice sessions separated with a minimum of 3 days were held to familiarize all participants with the training and testing protocols. Each of them focused solely on one of the training protocols. In the following two weeks, participants attended two testing sessions, which were separated by 1 week and performed

at the same time of day. All sessions were preceded by a warm-up consisting of five minutes of cycling on an ergometer at 50 watts and 60 rpm, followed by fifteen seconds of skipping and eight free bodyweight squats.

Practice sessions. Measurements of body mass, height, body mass index and % fat mass were performed. Afterwards, the participants practiced the squat exercise that would be performed during testing. The technique of performance was assessed by researchers and instructions were given to each participant to perform the exercise properly. The familiarization movements were performed with low loads and the participants repeated the exercise until they felt confident. Furthermore, a progressive test was completed to determine the peak power (P_{max}) and define the load to be used during the testing sessions. Finally, the SJ test was explained and the participants were instructed to perform the jumps at the angle required for the evaluation.

Testing sessions. After the warm-up and before performing the baseline SJ test, the skin temperature of the thigh and blood lactate concentration were measured. These control variables were recorded to ensure that both protocols were carried out under the same muscle conditions. Next, the SJ was evaluated. Two SJs were performed with a rest interval of 30 s. The average of the two jumps was recorded as baseline value, and these data were also used to calculate the intraclass correlation coefficient (ICC) between sessions. Once this measurement was done, the protocols started.

The TP was performed in a Smith machine with a guided barbell (Shock Multipower, Telju Fitness, Spain), which reduced variability among subjects by standardizing squat technique (Figure 1). The guided barbell was centered on the shoulder and feet shoulder width apart. The TP consisted of 3 sets of 6 bilateral repetitions of the half squat (knee flexion of 90º) at P_{max} (with a workload of 68 ± 5.7% 1RM), and 3 min rest intervals between sets. The participants were asked to perform the protocol with a tempo of 1/0/0.5/0 (Wilk et al., 2018) (1-s eccentric phase, no break in the transition phase, a 0.5-s concentric phase and no rest before the next repetition), trying to reach the maximal velocity in the concentric phase. The participant's feet did not leave the ground and the barbell was not allowed

to leave the participant's shoulders.

The IFP was performed using an inertial flywheel device (Eccoteck training force, Byomedic Systems, Spain). This device consists of a cone that is attached above the flywheel, and a tether that is rolled or unrolled when the cone rotates, generating a momentum of inertia. The flywheel weighed 3 kg and an extra load in opposition could be coupled to increase the momentum of inertia. Each extra load weighed 462 grams and the distance from the rotating cone to the extra load was 11.5 cm. The tether from the flywheel device was passed through a round pulley anchored to the ground and hooked to a hip belt of the tested participant. The participant was in an upright position, at a distance of 1.50 m from the device, with shoulders and hip joints in alignment, and feet shoulder-width apart (Figure 1). The training protocol consisted of 3 sets of 6 bilateral repetitions of the half squat at P_{max}, and 3 min rest intervals between sets. Participants were requested to lift the load with the same tempo as in the TP, which ranged from 90º knee flexion to near full extension. During the eccentric actions, participants had to resist gently and break the movement at about 90º knee flexion.

Later, 1 min after completing the protocol, the final blood lactate sample was taken. Four minutes after the stimulus, and just before performing the SJ, the skin temperature was measured again. At this time, the PAP effect was evaluated by the SJ that was performed at the 4th, 8th and 12th minute after the end of the activating exercise. Finally, 30 minutes after the PAP stimulus, the rated perceived exertion (RPE) was also assessed to determine the internal load of the both protocols.

Measures

Several anthropometric measurements were taken at the beginning of the first practice session to characterize the individuals. Body height was evaluated using a portable stadiometer (Seca 213, Germany). Body mass, body mass index and % fat were assessed using a bioelectrical impedance analyzer (BF-350, Tanita Europe BV, The Netherlands). Hydration prior to body composition testing was not allowed.

P_{max} was calculated in the practice sessions to determine the load to be used during the testing sessions. The equipment and techniques employed were the same as during the

testing sessions. In accordance with the measurement protocol proposed by de Hoyo et al. (2015), each participant had to perform an incremental protocol. The participants were positioned in a half squat position (knee flexion of 90º), both in the TP and IFP, and were instructed to extend the knees fully. For the concentric phase, the participant was instructed to move the load as quickly as possible in an attempt to maximize power output, and this movement was repeated four times. After a rest interval of 3 minutes, the load was increased by 5-10 kg in the TP, or by 2 extra loads (924 g) positioned facing each other inside the flywheel in the IFP. The test finished when there was a decrease in power output as compared with the previous trial. Power output was measured by a linear transducer or a rotary axis encoder (Chronojump Encoder, Boscosystem, Spain) coupled to the guided barbell or to the flywheel device, respectively. The loads that maximized the peak power during both protocols were 74.3 ± 15.9 kg (to develop P_{max} = 1127.2 ± 428.4 Watts) in the Smith machine, and 7.53 ± 0.90 kg (to develop P_{max} = 1007.6 ± 291.5 Watts) in the flywheel device.

During the testing session, all SJs were performed on a portable contact platform (Chronojump; Boscosystem, Spain) where data of jump height, velocity and power were instantaneously recorded by free software distributed by the manufacturer (Software chronojump V1.8.0, Boscosystem, Spain). The participants started from a stationary squat position (90°), with hands on the hips, before jumping upwards. On the command, the participant extended their knees and jumped as high as possible while maintaining the hands on the waist and landed with both feet. Baseline measurement was the average value of two squat jumps performed after the warm-up and separated by 30 s. Subsequently, after the PAP stimulus, another SJ was performed and recorded at the 4th, 8th and 12th minute.

Skin temperature was measured from the thigh of the right leg by an infrared thermometer (TAC 5000, Exergen, USA) to check that the temperature was the same under both conditions. Temperature was taken before the baseline SJ and just before the SJ performed 4 min after the PAP stimulus.

Capillary blood lactate and the RPE were analyzed to determine the internal load during the testing sessions and verify whether the results obtained were not due to possible differences in the fatigue level induced by both protocols. Samples were drawn from the fingertip of participants before the baseline SJ and 1 min after the PAP stimulus. Lactate concentration was measured with a fast and reliable portable analyzer (Lactate Scout+, SensLab GmbH, Germany) that uses an enzymatic–amperometric detection method and requires only 0.5 µL of blood. The RPE was assessed by the OMNI-Resistance Exercise Scale (OMNI-RES) which is a validated RPE for resistance exercise (Robertson et al., 2003). The OMNI-RES consisted of 10 reporting options between 1 (extremely easy) and 10 (extremely hard). Thirty minutes after finishing the protocols, a copy of this scale was given to the participants and they rated how hard the whole training session had been.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 23.0. (IBM Corp., Armonk, New York, USA). The Shapiro-Wilk test was applied to verify a normal distribution of data and the Levene´s test was used to assess the homogeneity of variance. A two-way analysis of variance with repeated measures and the Bonferroni post hoc test were conducted to evaluate the potentiation effect on dependent variables (SJ height, velocity and power). The factors were protocols (traditional and inertial flywheel) and time with 4 levels (baseline, 4 min, 8 min and 12 min). The time x protocol interaction effect was tested using the multivariate criterion of Pillai's trace. Reliability was determined according to the ICC with 95% confidence intervals between the two testing sessions. The ICC was calculated between the baseline values obtained in the squat performed in the inertial flywheel session and the squat performed in the traditional session. Moreover, standard error of measurement (SEM) and smallest real difference (SRD) were assessed to detect the real variation in the dependent variables (Beckerman et al., 2001). In order to facilitate the interpretation and comparison of results with other studies, SEM% ([SEM/mean values of 2 testing sessions] x 100) and SRD% ([SRD/ mean values of 2 testing sessions) x 100] were shown. The effect size (ES) was calculated

for all dependent variables over time using the Cohen's d. The magnitude of effect was classified as trivial (0.25), small (between 0.25 and 0.50), moderate (between 0.50 and 1.0) and large (>1.0). On the other hand, a one way ANOVA was performed to analyze differences of skin temperature, blood lactate concentration and RPE values between protocols. The significance level was set at $p \leq 0.05$, with a confidence level of 95%. Means and standard deviations (SD) were used as descriptive statistics.

Results

Table 1 shows the potentiation effects on the SJ after both protocols. There were significant increases of SJ height ($p = 0.004$, ES = 0.665), velocity ($p = 0.003$, ES = 0.688) and power ($p = 0.004$, ES = 0.682) from baseline after the IFP. Effect size for the improvement in all dependent variables was moderate (greater than 0.60). Post hoc analyses revealed that the IFP significantly improved the performance of the SJ in

comparison to baseline at the 4th and 8th minute after completing the protocol. No significant difference was observed after the traditional protocol in any variable.

Table 2 shows the ICC values and measurement errors between testing sessions. All dependent variables had an ICC greater than 0.95. The values of SEM% ranged from 2.2 to 2.6% and the values of SRD% ranged from 6.2 to 7.2%. These data indicated that the measurements taken could be considered reliable.

A significant interaction effect (time x protocol) was observed (Figure 2), showing that the IFP had a potentiation effect on performance (SJ height, velocity and power) compared to the TP, specifically at the 4th and 8th minute after the PAP stimulus.

No significant difference was observed between protocols in the variables used to monitor the internal load such as skin temperature, blood lactate concentration and the RPE (Table 3).

Table 1

Potentiation effects on squat jump performance after both protocols (Mean ± SD)

Protocols	Variables	Baseline	SJ 4′	SJ 8′	SJ 12′	*p*	d
Traditional protocol	Height (cm)	27.83 ±5.71	27.83 ± 5.51	27.38 ± 5.68	27.10 ± 6.15	0.614	0.135
	Velocity (m/s)	2.32 ± 0.25	2.32 ± 0.24	2.30 ± 0.24	2.29 ± 0.26	0.557	0.153
	Power (W)	807.94 ±182.67	806.31 ± 172.51	801.29 ± 179.90	797.06 ± 183.51	0.638	0.127
Inertial flywheel protocol	Height (cm)	26.97 ± 5.26	28.82 ± 5.77 *	28.87 ± 5.94 *	26.72 ± 6.17	0.004	0.665
	Velocity (m/s)	2.25 ± 0.23	2.34 ± 0.25 *	2.34 ± 0.27 *	2.27 ± 0.27	0.003	0.688
	Power (W)	782.55 ±173.15	818.40 ± 192.54*	816.71 ± 184.99*	791.80 ± 185.84	0.004	0.682

*Significant differences from baseline ;
SJ: Squat Jump; p: Significance level; d: Effect size (Cohen's d)

Table 2

Between day intraclass correlations for chosen variables.

Variables	ICC	SEM	SEM%	SRD	SRD%
Height (cm)	0.98	0.694	2.532	1.923	7.019
Velocity (m/s)	0.95	0.071	2.613	0.197	7.243
Power (W)	0.99	12.056	2.261	33.419	6.267

ICC: intra-class correlation coefficient
SEM: Standard error of measurement;
SRD: Smallest real difference.

Table 3

*Variables used to monitor the internal load of the exercise protocol (Mean ± SD).*

Protocols	Skin temperature		Blood lactate		RPE scale	
	Pre	Post	Pre	Post	Pre	Post
Traditional protocol	29.71 ± 1.22	30.03 ± 1.21	1.52 ± 0.28	4.20 ± 1.38	0	6.83 ± 1.93
Inertial flywheel protocol	30.11 ± 1.19	30.44 ± 1.28	1.48 ± 0.31	4.06 ± 1.21	0	6.00 ± 1.47
p	0.372	0.372	0.835	0.760	-	0.195

p: level of significance

Figure 1

Half squat techniques performed in both protocols.
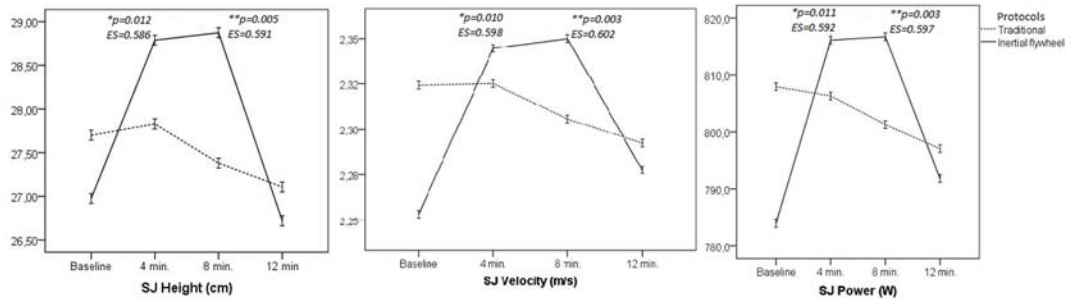
Figure 2

Time x Protocol interaction effects on SJ performance over time.

Discussion

This study is the first research to observe the PAP effect of an inertial flywheel protocol on SJ performance. The results showed that the SJ significantly increased after the IFP, whereas the TP did not induce any improvement.

The rotational inertia during flywheel exercise causes a greater eccentric overload than that produced by the traditional resistance exercise (Maroto-Izquierdo et al., 2017). The type II muscle fibers are highly recruited during eccentric contractions, a very relevant fact since the PAP effect has been observed especially in this type of muscle fibers (Rixon et al., 2007). Consequently, the eccentric overload could

explain the potentiation effect observed after our flywheel protocol. Indeed, Gołaś et al. (2016) showed that eccentric supramaximal intensities (130% 1RM) could be effective in eliciting PAP in strength trained individuals. Similar results to those shown in our study were observed in swimmers who improved power output after using a YoYo flywheel device in a previous warm up (Cuenca-Fernández et al., 2015). However, some research has concluded that the use of augmented eccentric loads prior to a 30% 1RM squat jump failed to acutely enhance force, velocity and power (Moore et al., 2007). An explanation for this conflicting result may be that the volume and intensity of the preconditioning exercise performed during the aforementioned study (only 2 sets of 1RM with eccentric loads of 20, 50, and 80% of the back squat 1RM) were not sufficient to cause a potentiation effect.

Other factors could also explain the PAP effect on jump performance after using the flywheel device. On the one hand, the eccentric-concentric transition during flywheel training activates a powerful stretch-shortening cycle (Martinez-Aranda and Fernandez-Gonzalo, 2016). This stretch reflex could potentiate the force peak of a subsequent explosive action due to the use of stored elastic energy (Wilson and Flanagan, 2008). Previous studies have shown an acute improvement in vertical jump performance after a warm-up with specific jumping exercises, in which the stretch-shortening cycle played an important role (Chen et al., 2017). In addition, every subject in our study performed the IFP with an individual training load (inertia), that allowed to reach peak power and maximal possible velocity during the movement. The high movement velocity may have a positive PAP effect on performance and power, increasing the neuromuscular activation (de Hoyo et al., 2015). Suchomel et al. (2016) concluded that the potentiation effect on jump performance was greater when half-squat exercise was performed with maximal velocity compared to without maximal velocity. On the other hand, the relative contribution of the joints to the movement is different when comparing exercises performed with traditional weights or with an inertial flywheel. The squat exercise performed with flywheel resistance had greater impulse requirement of the hip and ankle compared to free weight (Chiu and Salem, 2006). This fact could indicate that during our IFP there was a pre-activation of a greater number of muscle fibers than when the TP was performed, which favored a better potentiation effect on the SJ.

Regarding the PAP effect after the TP, no improvement was observed in the subsequent SJ. Previous studies have concluded that the fatigue level after the preconditioning activity can increase and reduce the ability to cause PAP (Lowery et al., 2012). However, it is important to note that there were no significant differences in blood lactate concentration and the RPE when comparing both protocols. Therefore, the level of fatigue would not be the variable that explains the lack of potentiation effect after the TP. The lack of improvement in the SJ could also be influenced by the muscle temperature. A decrease in muscle temperature has been associated with a fall in muscle power (Fletcher, 2013). However, we observed in our study that the temperature in both protocols was similar. Consequently, we should seek the explanation of this lack of improvement after the TP in other factors, such as the volume, intensity or type of conditioning exercise. Hanson et al. (2007) also did not find a PAP effect on the countermovement jump (CMJ) after performing squat training with light loads (8 repetitions at 40% of 1RM) and high velocity. On the contrary, several studies have reported increases in jump performance after a heavy-squat protocol lifting 2-5 RM (Chen et al., 2017; Fukutani et al., 2014), which contrasts with the findings of our study. These conflicting results could be explained by the fact that the TP of the present study had lower intensity and higher volume of repetitions.

On the other hand, the SJ improved at the 4th and 8th minute after the IFP, while this potentiation effect disappeared at the 12th minute. Previous reviews have showed that the greatest PAP effect is realized after longer recovery intervals (4-8 min) than after a shorter rest interval (2-3 min), although inter-individual variability was observed (Seitz and Haff, 2016; Wilson et al., 2013). These results are similar to those found by Lowery et al. (2012), who observed that the squat jump height increased and peaked from the 4th to 8th min and returned to baseline by the 12th min after performing a back squat exercise at 93% 1RM. During the first 4

minutes, the fatigue can dominate and reduce the performance, but later the fatigue would dissipate and the potentiation appears. In this sense, untrained individuals take longer to recover (about 8 minutes) and to achieve the maximum PAP responses (Seitz et al., 2014), as it happened in our study. In addition, afferent excitability caused by the muscle contraction is reported to persist for 3-10 min post exercise (Trimble and Harp, 1998), which is consistent with the time course of potentiation in our study that returned to baseline values by the 12th min.

The present study had some limitations, such as the lack of data for other blood variables so as to be able to evaluate muscular fatigue and neuromuscular excitability. Moreover, the squat protocols were performed with a single load on a specific range of movement, thus further research is required to corroborate the effectiveness of the inertial flywheel to potentiate the SJ.

In conclusion, the IFP showed a potentiation effect on the SJ between the 4th and 8th

minute after the exercise. However, the TP with a load that maximized power did not have any potentiating effect on performance of the SJ. These findings are of practical relevance for coaches and athletes who could use the inertial flywheel device to potentiate squat jump performance. This pre-conditioning strategy could be useful during the warm-up before competition, specifically in sport disciplines including explosives actions. The time interval between the 4th and 8th min after the preconditioning activity provides the greatest potentiation effect, thus the coaches should properly organize warming activities taking into account this time lag. Anyway, given that the PAP phenomenon depends on many variables, it remains important to individualize the conditioning protocol to the greatest possible extent.

Acknowledgements

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