IMPACT OF AN ACTIVATION PROTOCOL ON JUMP AND ACCELERATION PERFORMANCE IN HIGH JUMP ATHLETES

IMPACTO DE UN PROTOCOLO DE ACTIVACIÓN EN EL RENDIMIENTO DE SALTO Y ACELERACIÓN EN SALTADORES DE ALTURA

Javier Sanchez-Sanchez[1], *Jesús M. Luis-Pereira*[1], *Manuel Carretero-González*[1]

[1] Research Group on Training Planning and Performance Evaluation (PRENDE), Universidad Pontificia de Salamanca, España

Autor para la correspondencia:
Javier Sanchez-Sanchez, jsanchezsa@upsa.es

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Abstract

The aim of the study was to analyze the improvement in performance in jumping and acceleration actions of high jumpers, induced by a warm-up that included a post-activation performance enhancement (PAPE) stimulus based on a squat exercise with a load moved at an average propulsive velocity of 0.8 m/s. Twenty high jumpers (age: 20.8 ± 0.5 years) were divided according to strength levels into a strong group (GF: *n* = 10) and a weak group (GD: *n* = 10). The participants completed a control condition (PAPE0), after 10min of rest, a specific warm-up consisting of squats with a load moved at an average propulsive velocity of 0.8 m/s (PAPE100) was performed. After PAPE100, and following a 4-minute recovery, a vertical jump with counter-movement (CMJ) test was conducted. In another session, the same protocol was followed, including the acceleration test over 5 (5M) and 10 meters (10M). The main findings showed better performance in CMJ, 5M, and 10M after PAPE100 compared to PAPE0 (p<.05). No significant performance improvements were observed when comparing GF with GD. Significant differences (p<.05) were observed when comparing the CMJ jump test with 5M and 10M. In conclusion, warm-up protocols using PAPE100 loads can improve jumping and acceleration performance, regardless of participants' strength levels.

Keywords: Acceleration, exercise, sports performance, vertical jump, warm-up exercise.

Resumen

El objetivo del estudio fue analizar la mejora del rendimiento en acciones de salto y aceleración de saltadores de altura, provocada por un calentamiento que incluyó un estímulo de mejora del rendimiento postactivación (PAPE), basado en un ejercicio de sentadilla con una carga que se desplazaba a una velocidad media propulsiva de 0.8 m/s. Veinte saltadores de altura (edad: 20.8 ± 0.5 años) fueron divididos en función de los niveles de fuerza en un grupo de atletas fuertes (GF: *n* =10) y grupo de atletas débiles (GD: *n* =10). Los participantes completaron una situación control (PAPE0) separada 10minutos deuna activación específica basada en un ejercicio de sentadilla con una carga que se movilizada a una velocidad media propulsiva de 0.8m/s (PAPE100). Después de PAPE100, y tras 4minutos de recuperación, se realizó un test de salto vertical con contramovimiento (CMJ). En otra sesión, se siguió el mismo protocolo incluyendo el test de aceleración sobre 5 (5M) y 10 metros (10M). Los principales hallazgos mostraron mejor rendimiento en CMJ, 5M y 10M después de PAPE100 que de PAPE0 (p <.05). Sin embargo, no se observaron mejoras significativas en el rendimiento al comparar GF con GD. Por otra parte, el porcentaje de cambio asociado a PAPE100 fue significativamente mayor (p < .05) en CMJ que en 5M y 10M. En conclusión, la implementación del protocolo de activación PAPE100 puede ser una estrategia efectiva para mejorar el rendimiento en saltos y carreras cortas en atletas de salto de altura, independientemente de los niveles de fuerza de los participantes.

Palabras clave: Aceleración, ejercicio, ejercicio de calentamiento, rendimiento deportivo, salto vertical.

Introducción

In the field of sports training, warm-up has become a fundamental practice to enhance performance and prevent injuries(McGowan et al., 2015; Woods et al., 2007). To achieve this purpose, warm-ups were traditionally organized in a sequence of general activities followed by specific exercises, with the main goal of increasing body temperature(Towlson et al., 2013), thereby triggering a cascade of psychophysiological responses that prepared the athlete for maximal physical effort (Jeffreys, 2019). However, this methodology has been debated due to potential premature fatigue resulting from prolonged exposure to low-intensity aerobic stimuli, which could compromise performance in the medium term (Zois et al., 2015). Consequently, warm-up strategies have evolved to include high-intensity exercises, aiming to enhance neuromuscular capacity and optimize immediate performance (Afonso et al., 2024). This phenomenon is known as post-activation performance enhancement (PAPE) (Cuenca-Fernández et al., 2017).

PAPE is associated with increases in strength, power, and speed following the application of a stimulus that elevates muscle temperature and optimizes intramuscular coordination patterns (Boullosa et al., 2020). Although recent evidence has confirmed the existence of this phenomenon (Blazevich & Babault, 2019), it is challenging to determine the optimal characteristics of the stimulus that elicits it, in terms of intensity and load volume, recovery time, and the relationship between conditioning activity and performance activity (Wilson et al., 2013). This is because the same workload can produce different results depending on the characteristics of the athletes (Sanchez-Sanchez & Rodríguez-Fernández, 2025), particularly their strength levels (Sanchez-Sanchez et al., 2018). This is illustrated by a study on rugby players, which found that stronger individuals exhibited earlier and greater PAPE responses than weaker players after performing a set of squats at 90% of their one-repetition maximum (1RM) (Seitz et al., 2014). Similarly, a study with 28 healthy men compared the PAPE response using a gravitational load stimulus (i.e., free weight) versus a non-gravitational load (i.e., inertial device), finding that stronger individuals showed significantly greater sprint improvements when using the inertial device (Sañudo et al., 2020). Finally, a recent study with 13 elite sprinters found that three repetitions of squats at 90% 1RM improved static jump performance for 3–9 minutes, with more pronounced effects in the stronger sprinters (Guo et al., 2023).

Therefore, analyzing the effect of strength level son PAPE utilization is essential, as understanding this relationship can optimize training strategies and maximize performance in thes specialized athletes (Sanchez-Sanchez et al., 2016). In particular, for high jumpers, whose performance largely depends on power, research on PAPE application is scarce, despite its potential to provide significant benefits in improving performance. The aim of this study was to analyze performance enhancement in jumping and acceleration actions in high jumpers, induced by a warm-up that included a PAPE stimulus based on a squat exercise with a load moved at a mean propulsive velocity of 0.8 m/s. Our hypothesis was that the activation protocol would improve CMJ, 5M, and 10M performance in high jumpers, with more pronounced effects in those with higher strength levels.

Materials and Methods

Participants

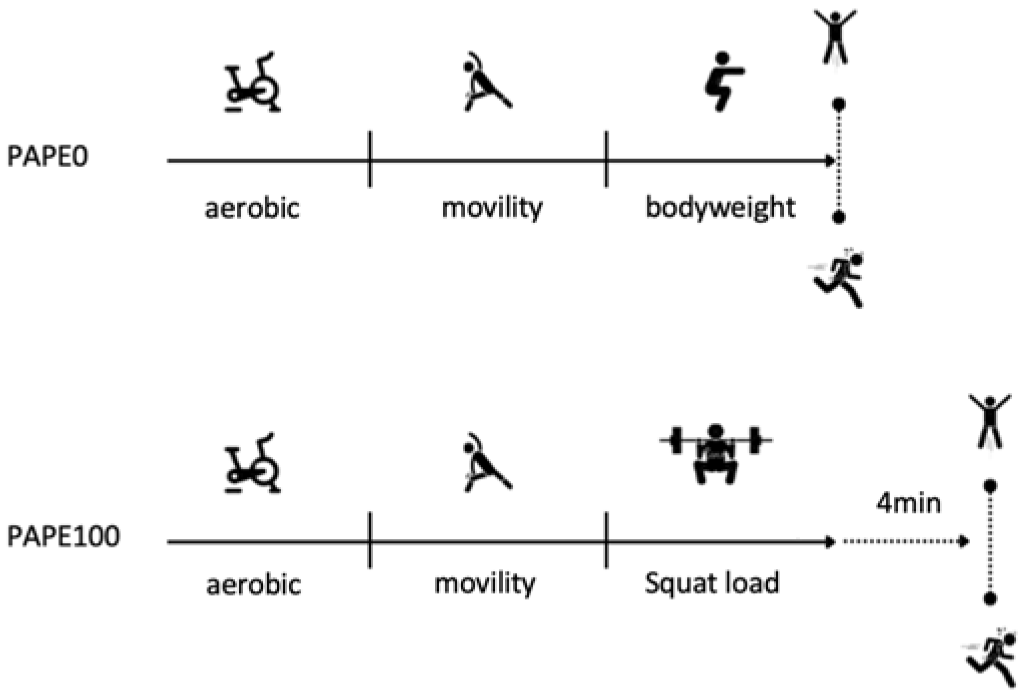
The study included 20 athletes (age: 20.8 ± 0.5 years; height: 181.4 ± 6.3 cm; body mass: 69.1 ± 7.4 kg) specializing in high jump, with systematic training experience in their discipline of 10.5 ± 1.3 years. All athletes belonged to the same athletics club and were classified at Level 3 according to the Participant Classification Framework (McKay et al., 2022). Their regular training comprised 4–5 weekly sessions of 60–90 minutes each of specific practice. Inclusion criteria for participation were: i) no previous musculoskeletal injury in the 3 months prior to data collection; ii) and maintaining regular training during the 6 months preceding the study. For the analysis of dependent variables, participants were divided based on their strength levels in the squat exercise at 0.8 m/s into a strong group (SG: n = 10; strength, 88.1 ± 13.1 kg; 9.8 ± 1.8 reps until 5% velocity loss) and a weak group (WG; n = 10; 54.2 ± 11.5 kg; 9.4 ± 2.1 reps until 5% velocity loss). The technical staff of the participating club authorized the study, and prior to its commencement, each participant signed informed consent detailing the procedures, risks, and benefits associated with participation in the experimental design. The experimental design adhered to the Declaration of Helsinki and was approved by the local Ethics Committee (code: Annex III, Act 13/2/2019).

Procedure

A counterbalanced, controlled, and randomized trial was conducted in this study to compare the power performance of high jump athletes after completing a PAPE activation protocol. Data collection occurred during the first half of the season, coinciding with indoor winter competitions. The study spanned 4 weeks, with the first week dedicated to two familiarization sessions allowing participants to become acquainted with the activation protocols and evaluation tests. During the squat exercise, athletes positioned the bar behind the neck at shoulder height, with feet shoulder-width apart and knees and hips fully extended. From this position, athletes performed an eccentric movement until reaching 90° knee flexion, followed by a concentric phase executed at maximal velocity, extending hips, knees, and ankles without lifting the feet off the ground or making a deliberate pause or rebound between phases. Adhesive markers on the floor and bar were used to standardize hand and foot positions, and an adjustable seat was placed behind participants to maintain consistent bar displacement and knee angle. After the warm-up, four progressive load sets were performed, increasing by 10 kg per set, with 2 repetitions at maximal concentric velocity per set, and 3 minutes of recovery between sets (Sanchez-Sanchez et al., 2024). Mean propulsive velocity (concentric) during the test was measured using a SmartCoach Power Encoder® (SmartCoach Europe AB, Stockholm, Sweden) and SmartCoach™ software (v5.6.0.8), which provided feedback to athletes after each attempt and enabled the collection of individual load-velocity profiles.

Figure 1

General Scheme of the Experimental Protocol



Note. PAPE0: general warm-up without PAPE stimulus; PAPE100: warm-up that included a squat with a load moved at a mean propulsive Velocity of 0.8 m/s.

Measurements

Progresive Load Test

Participants performed a progressive load test in the squat exercise following procedures described in previous studies (González-Badillo & Sánchez-Medina, 2010). The test was conducted on a BH L350B Smith Multipower Machine (BHFitness®, Vitoria-Gasteiz, Spain), with the bar restricted to vertical movement. The test was preceded by a standardized warm-up, executed by all athletes under the supervision of the same principal investigator. This warm-up included joint mobility exercises for the upper and lower limbs, followed by 2 sets of 8 repetitions with a 20 kg load for each exercise, with 3 minutes of recovery between sets (Sanchez-Sanchez et al., 2024). During the squat exercise, athletes positioned the bar behind the neck at shoulder height, with feet shoulder-width apart and knees and hips fully extended. From this position, athletes performed an eccentric movement until reaching 90° kneeflexion, followed by a concentric phase executed at maximal velocity, extending hips, knees, and ankles without lifting the feet off the ground or making a deliberate pause or rebound between phases. Adhesive markers on the floor and bar were used to standardize hand and foot positions, and an adjustable seat was placed behind participants to maintain consistent bar displacement and knee angle. After the warm-up, four progressive load sets were performed, increasing by 10 kg per set, with 2 repetitions at maximal concentric velocity per set, and 3 minutes of recovery between sets (Sanchez-Sanchez et al., 2024). Mean propulsive velocity (concentric) during the test was measured using a SmartCoach Power Encoder® (SmartCoach Europe AB, Stockholm, Sweden) and SmartCoach™

software (v5.6.0.8), which provided feedback to athletes after each attempt and enabled the collection of individual load-velocity profiles.

Vertical Jump Test

To assess vertical jump ability, the CMJ test was used, from which jump height in centimeters was recorded (Globus Ergo System®, Codogné, Italy). The CMJ was performed following previous recommendations (Maulder & Cronin, 2005), indicating minimal trunk flexion during take-off, arms fixed and placed on the hips, and full knee and hip extension during the flight phase.

Acceleration Test

Acceleration performance was recorded using a dual photocell system (Witty, Microgate®, Italy), positioned at the start line and at 5 m (i.e., 5M) and 10 m (i.e., 10M) to measure participants' acceleration capacity (Bevan et al., 2010). Athletes were encouraged to exert maximal effort, and performance was recorded as the time taken in seconds.

Warm-up Protocols

The PAPE0 condition consisted of a general warm-up comprising 5 minutes of aerobic exercise on a stationary bike at 60–70% of theoretical maximum heart rate, monitored via a Polar heart rate monitor (Polar Team Pro 2 Sensor®; Polar Electro, Kempele, Finland) connected to a display visible to participants at all times. This was followed by 5 minutes of a neuromuscular activation protocol using bodyweight exercises, performed in 2 sets of 20 seconds per exercise (Figure 2). Following previous guidelines (Cuenca-Fernández et al., 2015), this protocol included ankle plantar and dorsal flexion, hip flexion-extension, hip abduction-adduction movements, high knees in place, heel kicks, squats, and unilateral lunges using bodyweight. Finally, 2 sets of 5 unweighted squats were performed every 30 seconds, alternating tempos of 2/2 and 1/1 (eccentric/concentric).

Figure 2

Neuromuscular Activation Exercises Included in the General Part of the Warm-up Protocols

In the PAPE100 condition, the same sequence as PAPE0 was performed, but the unweighted squat was replaced with one performed with a load moved at a mean propulsive velocity of 0.8 m/s, applying a light effort characterized by a 5% velocity loss.

Statistical Analysis

Data are presented as mean ± standard deviation (SD). Data normality was verified using the Shapiro-Wilk test. To compare the effect of different PAPE activation protocols (i.e., PAPE0 vs PAPE100) according to participants' strength, a repeated-measures ANOVA was conducted. When a significant interaction ($p < .05$) was detected, the Bonferroni post hoc test was applied. Differences were considered significant at $p < .05$. Effect size (*ES*) was calculated using *Cohen's d*, with the following criteria: trivial ($ES < 0.2$), small ($ES \geq 0.2$), moderate ($ES \geq 0.6$), large ($ES \geq 1.2$), and very large ($ES > 2$) (Hopkins et al., 2009). Finally, t-tests were conducted to analyze group membership (SG vs WG) and test type (CMJ vs 5M vs 10M). All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, version 25.0 for Windows, SPSS Inc., Chicago, IL, USA).

Results

Table 1 presents the results obtained in the CMJ test and the 5M and 10M acceleration tests after PAPE0 and PAPE100.

The analysis of CMJ performance showed better results in this test after PAPE100 than after PAPE0, both in the SG (*p* = .002; *d* = 1.2; *diff* = 12.16 ± 11.57%) and in the WG (*p*< .001; *d* = 1.4; *diff* = 9.11 ± 4.74%). However, no significant differences were observed (*p* = .232; *d* = 0.3) in the improvement in CMJ after PAPE100 between SG and WG.

Regarding acceleration performance, results showed improvements in 5M and 10M after PAPE100 in both SG (*p*< .05; *d* = 0.8; *diff* = 3.54 ± 4.40 and *p*< .01; *d* = 1.1; *diff* = 2.96 ± 2.63, respectively) and WG (*p*< .01; *d* = 0.9; *diff* = 3.88 ± 4.47 and *p*< .01; *d* = 1.6; *diff* = 3.37 ± 2.05, respectively). Analysis according to strength levels showed no significant differences in 5M improvements between SG and WG (*p*> .05; d = 0.1). Similarly, results in 10M revealed that the improvement with PAPE100 compared to PAPE0 was 2.96 ± 2.63% in SG and 3.37 ± 2.05% in WG, with no significant differences between groups (*p* = .353; d = 0.2). Finally, analysis by test type showed that in both SG and WG, improvements were greater in CMJ than in 5M (*t* = 1.86; *p* = .048; *d* = 0.6 and *t* = 2.38; *p* = .021; *d* = 0.8, respectively) and 10M (*t* = 2.23; *p* = .026; *d* = 0.7 and *t* = 3.38; *p* = .004; *d* = 1.1, respectively).

Table 1

Resultados de los Test de Salto y Aceleración Tras la Aplicación de un Calentamiento PAPE0 y PAPE100

Group	Test	PAPE0	PAPE100	CMJ vs, 5M/10M
SG	CMJ (cm)	36.40 ± 4.59	40.58 ± 4.81**	a p = .048; d = 0.6b p = .026; d = 0.7c p = .243; d = 0.2
	5M (s)	1.11 ± 0.06	1.07 ± 0.07*	
	10M (s)	1.88 ± 0.07	1.82 ± 0.08**	
WG	CMJ (cm)	29.13 ± 4.79	31.8 ± 5.95**	a p = .021; d = 0.8b p = .004; d = 1.1c p = .341; d = 2.2
	5M (s)	1.17 ± 0.07	1.12 ± 0.08**	
	10M (s)	2.00 ± 0.12	1.94 ± 0.11**	

PAPE0: general warm-up without PAPE stimulus; PAPE100: warm-up that included a squat with a load moved at a mean propulsive velocity of 0.8 m/s. SG: strong athlete group; WG: weak athlete group. CMJ: countermovement vertical jump test; 5M: 5 m acceleration test; 10M: 10 m acceleration test; p: significance value; d: effect size.
a Indicates comparison CMJ vs 5M.
b Indicates comparison CMJ vs 10M.
c Indicates comparison 5M vs 10M.
* Indicates significant difference with PAPE0 (* p < .05; ** p < .01).

Discussion

The aim of this study was to analyze the improvement in jump and acceleration performance in high jump athletes following a warm-up that included a PAPE stimulus, based on a squat exercise with a load moved at a mean propulsive velocity of 0.8 m/s. The main findings showed better performance in CMJ, 5M, and 10M after PAPE100 compared to PAPE0. These results were obtained regardless of athletes' strength levels, as no differences were observed in the percentage change between SG and WG. Furthermore, when analyzing improvements according to test type, greater performance gains were observed in CMJ compared to 5M and 10M, suggesting a greater transfer of the PAPE effect to jumping actions than to acceleration.

Our results indicated that athletes achieved better results in jump and acceleration tests after performing PAPE100 activation compared to PAPE0. The se findings are consistent with previous studies showing improvements in CMJ after activation protocols with squats performed at 40%-100% of 1RM in young soccer players (Titton & Franchini, 2017), elite sprinters performing squats at 90% 1RM (Guo et al., 2023), collegiate rugby players performing squats at 5RM (Mitchell & Sale, 2011), and collegiate athletes performing squats at 80% 1RM (Naclerio et al., 2014). Regarding acceleration improvements, previous studies reported better 10M times in young soccer players performing deadlifts at 5RM (Till& Cooke, 2009) and in team sport athletes performing squats at 90% 1RM (Chatzopoulos et al., 2007). However, our findings differ from a study with collegiate soccer players that found no 10M improvements after performing 3 squats at 90% 1RM as an activation strategy (McBride et al., 2005). Although the mechanis ms underlying performance improvements in power actions after high-intensity loads are not fully understood (Boullosa et al., 2018), many studies suggest increased recruitment of type IIx motor units, elevated ATPase activity, regulation of antagonist muscle co-activation, or enhanced stretch-shortening cycle (Garbisu-Hualde & Santos-Concejero, 2021). These responses may optimize neuromuscular performance, manifesting in improved maximal strength, which appears to positively transfer to jump and acceleration capacity (Maroto-Izquierdo et al., 2020).

Individual athlete characteristics have been used to explain why some athletes improve their power performance after a PAPE stimulus while others show no changes or even decreased performance after high-intensity activation protocols (Mola et al., 2014). The most studied variables are strength levels and training experience, which condition the response to load (Wilson et al., 2013). Therefore, these characteristics must be considered to adapt intensity, volume, recovery time, and the activity performed to configure an optimal activation stimulus foreach athlete (Seitz &Haff, 2016).

In our sample, strength levels (i.e., SG vs WG) did not condition the response to the PAPE stimulus. However, this contrasts with other studies indicating a direct relationship between PAPE effect and strength levels (Guo et al., 2023; Sañudo et al., 2020), greater strength training experience (Chiu et al., 2003; Harat et al., 2020), and higher competitive level (Sanchez-Sanchez et al., 2018). The positive influence of strength on acute performance enhancement may be attributed to stronger athletes having more type IIx fibers (Hamada et al., 2000, 2003) and higher myosin light chain phosphorylation activity (Sale, 2004), allowing better neuromuscular readiness to respond to high-intensity stimuli (Bishop, 2003). In our study, the lack of a relationship between strength levels and PAPE effect may be explained by other modulating variables masking this relationship. Indeed, factors such as recovery time, intensity and volume of applied PAPE stimulus, and its specificity to the sport modality have been shown to considerably influence the effectiveness of activation stimuli (Wilson et al., 2013). Thus, in our design, these variables may have contributed to a response that did not reflect a differential impact based on strength levels, reducing their role as performance modulators.

Our findings indicate that high-intensity stimuli applied through the squat exercise transfer more effectively to jumping actions than to acceleration. This aligns with a study conducted with recreational athletes, where a load corresponding to 6RM in the half-squat exercise improved CMJ performance without changes in 5M acceleration (Beato et al., 2019). Although further research is needed, our results suggest a possible relationship between the force application vector during activation stimulus (i.e., squat and vertical force vector) and jump improvement (i.e., vertical force vector). Therefore, the specificity principle may be crucial in achieving PAPE effect, emphasizing the importance of selecting activities that respect competitive movement mechanics to improve performance in fundamental motor patterns (Seitz & Haff, 2016).

In light of our findings, applying submaximal squat loads during warm-up may be beneficial for enhancing CMJ and acceleration (i.e., 5M and 10M) performance in high jumpers. Coaches can use these protocols to optimize competitive performance, provided that load is individualized in terms of intensity, volume, and recovery time according to each athlete's characteristics. Additionally, respecting the specificity principle by selecting activation activities that mimic competitive movement mechanics ensures more effective transfer of warm-up benefits to performance during competition.

This study has several limitations to consider when interpreting the results. First, the small and homogeneous sample limits generalization to other athletic populations. Second, the relatively short study duration prevents evaluation of sustained PAPE effects. Finally, performance assessment focused on specific measures such as CMJ and 5M and 10M distances, providing a limited view of relevant performance aspects.

Conclusions

Implementing a submaximal load activation protocol can be an effective strategy to improve jump and short sprint performance in high jump athletes, regardless of strength levels. These findings suggest that using such loads generates specific benefits in vertical jump and acceleration capacity, which could be applied in pre-competition activation contexts to optimize performance in these actions.

Ethics Committee Statement

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Pontifical University of Salamanca (registration code: Annex III, Record 13/2/2019).

Conflict of Interest Statement

The authors declare no conflict of interest. The funding entities or institutions had no influence on the study design, data collection and analysis, or interpretation of the results.

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Authors' Contribution

Conceptualization: JSS and MCG; Methodology: JSS and MCG; Formal analysis: JSS and MCG; Investigation: JSS, LPJM, and MCG; Resources: JSS, LPJM, and MCG; Data curation: JSS and MCG; Writing – original draft: JSS and MCG; Writing – review & editing: JSS, LPJM, and MCG; Visualization: JSS and MCG; Supervision: JSS and MCG; Funding acquisition: JSS and MCG. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data supporting the results of this study are not publicly available due to ethical restrictions but can be requested from the corresponding author: Javier Sánchez Sánchez (jsanchezsa@upsa.es).

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