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Effects of post-activation performance enhancement with inertial device and VertiMax on agility: frequentist and Bayesian analyses

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Abstract
Introduction. **Agility, an essential aspect of various sports, has attracted increasing interest and has become a popular subject of research due to its direct influence on athletic performance.** Aim of Study. **The aim of this study was to analyze an acute effect of training with VertiMax and inertial devices as mechanisms for post-activation performance enhancement (PAPE) in physically active individuals.** Material and Methods. **A sample consisted of 27 participants with an average age of 24.33 ± 2.89 years. Participants were randomly assigned to three groups: An inertial RSP-squat device group, a VertiMax device group, and a control group.** Results. **Frequentist analyses revealed a significant interaction between pretest and posttest conditions, although no significant differences were found between the study groups. These findings were confirmed by Bayesian analyses. Both experimental groups and the control group showed reductions in race times, although a percentage of change was higher for a VertiMax training protocol. Additionally, it was observed that rest periods of approximately five minutes between measurements were more effective in improving athletic performance.** Conclusions. **Integration of PAPE-based training strategies with the use of devices can be crucial in optimizing athletic performance, although ongoing research is needed to inform practical and theoretical decisions in a field of physical conditioning.**

KEYWORDS: rest, muscular strength, eccentric, post-activation potentiation.

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Introduction

Agility, defined as an athlete's ability to quickly change direction, accelerate, decelerate, and execute explosive movements with efficiency and precision, plays a crucial role in numerous sports [23]. Its significance lies in a need for precise body control and swift responses to unexpected movements, which are fundamental in disciplines such as soccer, basketball, tennis, among others [10, 19]. Agility, an essential aspect in various sports, has sparked growing interest and has become a popular subject of research due to its direct influence on athletic performance [32]. Given its multifaceted nature, requiring a unique combination of strength, speed, coordination, and balance, optimizing agility becomes essential for athletes. In this context, research aimed at identifying effective training methods to improve agility becomes imperative.

Young and Farrow [31] proposed a comprehensive model for constituents of agility, organizing and categorizing training methods into two main branches: those based on strength training and those focused on coordination. The former concentrates on developing muscular strength necessary to generate power and accelerate a body, incorporating exercises such as squats, deadlifts, and jumps [5]. The latter focuses on improving a central nervous system's ability to coordinate movements, including practices like directional changes, slaloms, and obstacle courses [15]. Improving agility has been a central theme in sports science research, and various training methods have been explored for effective strategies. Among classical methods, plyometric training has proven effective in developing explosive strength and power, fundamental attributes for agility [11]. Jumps, box jump exercises, and other plyometric movements have been successfully implemented in training programs to enhance athletes' responsiveness and speed [3, 25]. In turn, muscular strength is an essential component of agility, and strength training or a weight overload has been explored in various contexts. Programs incorporating weightlifting with high repetitions and a low load, as well as elastic resistance methods, have shown improvements in muscle endurance and responsiveness [8].

On the other hand, improving agility involves not only strength and speed, but also coordination and balance. Methods focusing on proprioception development, such as exercises on unstable surfaces or specific balance training, have shown benefits in enhancing stability and coordination [24]. Additionally, their combination with other training methods, like plyometrics, has been beneficial for athletes [16].

High-intensity training, characterized by brief bursts of extreme activity followed by rest periods, has gained attention in literature. This approach not only improves cardiovascular capacity, but may also have positive effects on agility by enhancing a body's ability to recover rapidly between explosive efforts, although there is insufficient evidence of its specific effects on agility tests [29]. Furthermore, sport-specific movement technique is a critical component of agility. Training focused on perfecting cutting, turns, and sport-specific directional changes can be fundamental to improving agility in a sport context [7]. In summary, agility improvement is not achieved through a singular approach, but benefits from integration of various training methods addressing different aspects of athletic capacity. Although total time remains a typical unit of measurement for its assessment, different types of training may result in preferential improvements in acceleration, deceleration, or directional changes. Studying and comparing these methods will provide more comprehensive and strategic understanding of how to optimize agility performance.

In recent years, two innovative training methods that have shown promising results for enhancing agility have emerged: inertial devices and VertiMax. Inertial or rotational devices use variable weights to provide resistance. These devices, such as a flywheel or a conical pulley, provide an ability to generate a higher eccentric load than traditional weight training, without a need for heavy loads or complex setups. Additionally, they enable specific movements under various conditions and at high speeds [9]. This type of training involves eccentric and concentric contractions, resulting in greater strength and power production with less energy expenditure. It is also associated with preferential recruitment of high-threshold motor units, post-activation potentiation, and chronic adaptations in strength, power, or muscle hypertrophy, which can enhance athletic performance. The eccentric load can be increased by braking inertia at the end of a movement, a phenomenon known as an eccentric overload [18]. On the other hand, the VertiMax device uses elastic bands in a pulley system to provide resistance against a direction of movement, similarly contributing to activation of fast-twitch muscle fibers IIX and promoting musculotendinous adaptations for specific explosive actions or movements in sports [14]. Both methods contribute to a development of strength, speed, and coordination, essential elements for enhancing agility.

A specific comparison between training methods, such as inertial devices and VertiMax, is essential to determine which of these approaches may be more effective in enhancing agility. Given the constant evolution of sports training practices, understanding relative advantages of these methods can have significant implications for planning and execution of training programs.

Existing literature supports the idea that both inertial devices and VertiMax have shown potential in improving physical attributes relevant to agility. Inertial devices, by using variable weights, have shown benefits in an explosive strength development and other physical capacities [22, 28]. On the other hand, the pulleys or the elastic bands of VertiMax have been associated with improvements in speed and coordination [30]. However, a scarcity of studies directly comparing these two methods limits understanding of their differences and similarities in terms of effectiveness in improving agility. This gap in the literature underscores a need for a robust and systematic comparative study that sheds light on distinct contributions of inertial devices and VertiMax in the context of agility performance.

Aim of Study

In this context, the present study aims to analyze effects of two innovative training methods, VertiMax and the inertial device, as mechanisms for post-activation performance enhancement (PAPE) on agility in physically active individuals. The goal is to provide a deeper understanding of relative effectiveness of these emerging approaches to optimize performance in terms of agility.

Material and Methods

Participants

A sample size calculation indicated a sample size of 24 volunteers to achieve statistical power of 0.90, $\alpha = 0.05$, a correlation coefficient of 0.50, sphericity correction of 1, and an effect size of 0.30. This analysis aims to reduce a probability of Type II error by determining a minimum number of participants needed to reject the null hypothesis (confidence level of $p < 0.05$) [2]. A public call for participation in the study was made through social media and institutional emails from two private universities in Bogotá. A total of 40 individuals, both men and women, expressed interest and were registered in an online survey. After verification of inclusion and exclusion criteria, the sample consisted of 27 subjects, with an average age of 24.33 ± 2.89 years (21 men and 6 women), height of 168.7 ± 7.1 cm, and weight of 67.21 ± 8.42 kg. The participants were randomly assigned using permuted block randomization to balance both the number of participants and gender across the three groups: the VertiMax device group (VG), n = 9; the inertial RSP-squat device group (IG), n = 9; and the control group (CG), n = 9. The inclusion criteria considered being physically active with at least three or more days of systematic physical exercises per week, being of legal age, and being under 30 years old. The exclusion criteria included suffering from any musculotendinous injury or undergoing physical rehabilitation at the time of the study, cardiovascular or respiratory problems, or any pathology compromising participants' integrity during the study. Additionally, failure to complete all training sessions or assessments was considered the exclusion criterion.

Study Organization

The research project was approved by the Research Ethics Committee of the Corporación Universitaria Minuto de Dios (Act 04 of 2023). The study was conducted in a laboratory of the Faculty of Health and Sports Sciences of the Fundación Univeristaria del Área Andina (Bogotá, Colombia). After the public call, the eligible subjects were invited for measurements of body weight and height, followed by a familiarization session with the devices and an agility test. The subjects were then assigned to the groups, and intervention protocols were implemented on specific days for each group.

Assessment instruments

1. Agility Evaluation: The agility test utilized the T-Test by Pauole et al. [20], a recognized tool in scientific literature [26]. BlazePod® sensory devices recorded running times, activated by the participants at a start and finish, and displayed on an iPad 32 GB (Apple company).
2. Training Equipment. VertiMax®: Used for resisted jump training, simulating Abalakov jumps with specific resistance bands. Inertial Training (RSP Squat): Utilized an RSP Squat device with a SmartCoach velocity transducer, focusing on pushing and braking actions of lower limbs. The inertial device had a total load of 0.100 kg/m^2.

Intervention protocols

Experimental group – VertiMax (VG): The participants performed eight maximal intensity vertical jumps, simulating Abalakov jumps, using specific resistance bands.

Experimental group – Inertial Device (IG): The group executed two squats to generate inertia in the flywheel, followed by six repetitions at maximum concentric speed with controlled eccentric phases. The RSP Squat device had a load of four aluminum masses (240 g each, total 0.235 kg/m^2).

Control group (CG): The subjects performed pre- and posttests after a standardized warm-up, with no specific intervention other than the assessments.

Warm-up and post-intervention: A standardized warm-up, including muscle activation exercises (squats: two sets of five repetitions, vertical jumps: two sets of two repetitions) was conducted before the initial assessments. All groups performed the agility test after completing the training protocol at minutes two (2') and five (5').

Data analysis

The data met assumptions of homogeneity and homoscedasticity ($p < 0.05$). The two-way repeated measures ANOVA was employed to assess the effect of the training protocols within each group and between the groups, and the Bonferroni test was used for intergroup comparisons. Additionally, the Bayesian ANOVA was used as a contrasting measure to understand underlying relationships in the data. All analyses were conducted using the open-access software JASP®. A significance level of 0.05 was considered.

Results

The participant sample consisted of males (78%) and, to a lesser extent, females (22%). Detailed sociodemographic characteristics are presented in Table 1.

Frequentist analysis

The frequentist analysis of agility test displacement times reveals significant improvements in the groups that used the devices (VertiMax and inertial) in the posttest measurements, as shown in Table 2.

Table 1. Sociodemographic characteristics of the participants by group assignment

Variables	Group	Mean ± SD	Coe var	SW	p SW	Min.	Max.
Age (years)	Control	24.89 ± 3.41	0.14	0.96	0.84	20.0	30.0
	Inertial	23.56 ± 1.81	0.08	0.95	0.71	21.0	27.0
	VertiMax	24.22 ± 2.44	0.10	0.92	0.43	21.0	28.0
Height (cm)	Control	1.66 ± 0.07	0.04	0.96	0.75	1.57	1.78
	Inertial	1.71 ± 0.08	0.05	0.75	0.01	1.57	1.80
	VertiMax	1.69 ± 0.06	0.04	0.94	0.62	1.60	1.80
Weight (kg)	Control	63.46 ± 9.19	0.15	0.94	0.61	51.00	76.80
	Inertial	70.54 ± 8.58	0.12	0.95	0.67	56.10	81.20
	VertiMax	67.64 ± 6.65	0.10	0.98	0.98	57.70	78.40
Characteristics by gender							
Age (years)	Males	24.38 ± 2.50	0.10	0.98	0.89	20.0	30.0
	Females	23.67 ± 3.08	0.13	0.88	0.26	21.0	29.0
Height (cm)	Males	1.71 ± 0.06	0.04	0.96	0.48	1.57	1.80
	Females	1.61 ± 0.03	0.02	0.87	0.22	1.57	1.64
Weight (kg)	Males	69.53 ± 7.59	0.11	0.97	0.78	53.30	81.20
	Females	59.10 ± 6.13	0.10	0.98	0.92	51.00	67.90

Note: SD – standard deviation, p SW – Shapiro-Wilk p-value, SW – Shapiro-Wilk, Coe var – coefficient of variation.

Table 2. Pre- and post-test agility results

		Mean ± SD	Coe var	95% CI VU	95% CI VL	SW	*p* SW	Min.	Max.
Pre	Control	13.59 ± 1.66	0.12	3.81	1.02	0.93	0.45	11.26	15.80
	Inertial	12.93 ± 1.46	0.11	3.18	0.69	0.94	0.62	10.74	14.79
	VertiMax	13.46 ± 2.07	0.15	8.34	0.71	0.87	0.14	11.42	17.98
Post 2	Control	13.06 ± 1.45	0.11	3.19	0.71	0.96	0.81	11.00	15.37
	Inertial	12.63 ± 0.77	0.06	1.01	0.16	0.95	0.63	11.27	13.71
	VertiMax	12.23 ± 0.40	0.03	0.22	0.02	0.83	0.05	11.86	12.83
Post 5	Control	12.98 ± 1.29	0.10	2.48	0.43	0.92	0.40	11.44	15.16
	Inertial	11.92 ± 0.67	0.06	0.70	0.13	0.93	0.51	10.78	12.74
	VertiMax	11.93 ± 0.45	0.04	0.32	0.06	0.98	0.94	11.26	12.65

Note: SD – standard deviation, *p* SW – Shapiro-Wilk p-value, SW – Shapiro-Wilk, Coe var – coefficient of variation, CI – confidence interval, VU – variance upper, VL – variance lower.

The two-way repeated measures ANOVA analysis shows overall significant differences between the pre- and posttest measurements, with a significant main effect of rest periods [F = (1.15, 27.79) = 11.23, $p < 0.002$; $n^2p = 0.31$ (large effect size)], and a violation of Mauchly's sphericity assumption ($p < 0.01$). The Greenhouse-Geisser correction ($p < 0.75$) supports these differences. The post hoc analysis with the Bonferroni correction reveals a significant sequential decrease in the agility test displacement times between the pretest and a 5-minute rest period (p = 0.010) only in the VertiMax group.

The Greenhouse-Geisser correction indicates no significant interaction between the rest periods and the training type [F = (1.21, 27.79) = 1.21, p = 0.31; $n^2p = 0.09$]. No significant effect was observed for the type of training to generate PAPE [F(2, 24) = 1.274, $p < 0.29$; $n^2p = 0.09$]. Regarding simple main effects, a significant interaction between the rest period and the training types was evident [F(2) = 4.33, p = 0.02], indicating that the most suitable rest period to improve the agility test displacement time (PAPE) is approximately five minutes.

A percentage change in race times after the rest periods in the different groups compared to the pretest was as follows: at minute two, CG = 3.9%, IG = 2.3%, and VG = 9.1%; at minute five, CG = 4.4%, IG = 7.8%, and VG = 11.4%.

In summary, the statistical analysis of the displacement times in the agility test shows the significant improvements in the groups that used the devices (VertiMax and inertial), with slight changes even in the CG. Overall, significant differences were observed between the pre- and post-training measurements, especially in the VertiMax group. Furthermore, the rest period of approximately five minutes between the measurements appears to be more effective in improving the displacement time in the agility test.

Bayesian analysis

Table 3 presents model comparison, effects analysis, and post hoc tests.

Table 3. Model comparison, effects analysis, and post hoc tests

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Rest Intervals	0.200	0.553	4.954	1.000	
Rest Intervals + Groups	0.200	0.331	1.978	0.598	2.076
Rest Intervals + Groups + Rest Intervals * Groups	0.200	0.112	0.506	0.203	1.702
Null model (including subject and random slopes)	0.200	0.002	0.009	0.004	1.115
Groups	0.200	0.001	0.005	0.002	2.272
Effects	**P(incl)**	**P(excl)**	**P (incl|data)**	**P (excl|data)**	**BF_{incl}**
Rest Intervals	0.600	0.400	0.996	0.004	184.829
Groups	0.600	0.400	0.444	0.556	0.533
Rest Intervals * Groups	0.200	0.800	0.112	0.888	0.506
Post Hoc Comparisons – Rest Intervals		**Prior Odds**	**Posterior Odds**	**$BF_{10, U}$**	**error %**
Pre	2 min.	0.587	1.834	3.123	7.398×10^{-7}
	5 min.	0.587	28.944	49.275	6.372×10^{-8}
2 min.	5 min.	0.587	19.830	33.758	5.626×10^{-8}
Post Hoc Comparisons – Groups					
Control	Inertial	0.587	0.920	1.566	0.009
	VertiMax	0.587	0.561	0.955	0.009
Inertial	VertiMax	0.587	0.162	0.276	0.008

Note: P(M) – prior probabilities, P(M|data) – updated probabilities, BF – Bayes factor, incl – included, excl – excluded.

In summary, the Bayesian analysis supports that the rest periods of approximately five minutes between the measurements were more effective in improving the running times, especially for the group who used the VertiMax device. Additionally, significant improvements were observed in the groups that utilized the training devices (VertiMax and inertial) compared to the control group after this rest period.

Figure 1 presents mean posterior distributions of a model for the main effects. A clear separation between the pretest and the posttest at minute five is highlighted, reflecting shorter running time in the agility test (left-shifted curve). To a lesser extent, the results of the posttest at minute two compared to the pretest, although very close, remain separated without overlapping credible intervals. On the other hand, the distributions between the different types of training (VertiMax and inertial) and the control group overlap, both in density curves and the credible intervals. In summary, the figure clearly illustrates how the running times decreased in the posttest, especially at the 5-minute rest mark, indicating the improvements in agility. These findings underscore the importance of considering the rest periods and the type of training in optimizing athletic performance.

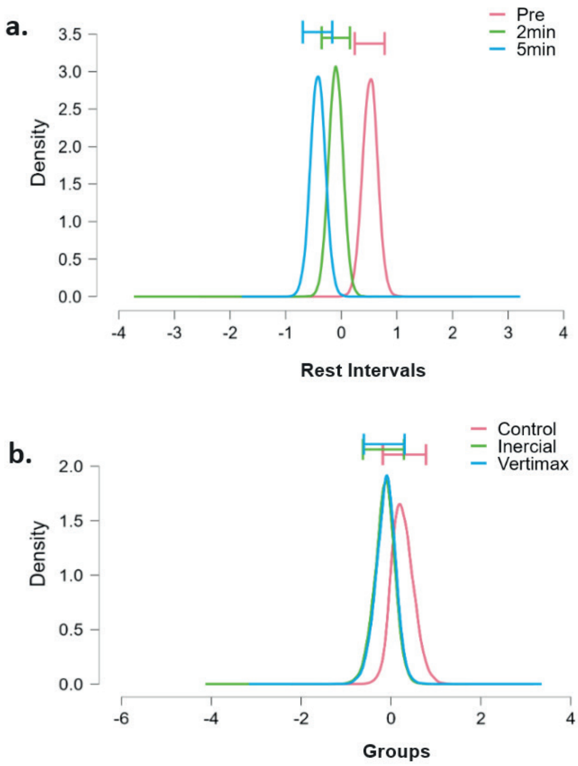

Figure 1. Mean posterior distributions of the model for main effects

Discussion

The present study aimed to assess the impact of the training methods, the VertiMax and inertial devices, on PAPE and its influence on agility in physically active individuals. It is crucial to mention that the two types of training used in this study are different. The VertiMax training employs resistance bands to generate an increased load during jumping exercises, involving both concentric and eccentric muscle contractions, and leveraging a myotatic reflex or the stretch-shortening cycle generated in each jump [12]. In contrast, the inertial training uses a flywheel device to generate resistance and mainly involves the concentric muscle contraction; the eccentric contraction arises from braking required to stop inertia of the device [13].

The frequentist results demonstrated the significant improvements in the agility test running times for both training groups. The Greenhouse-Geisser correction reveals that the type of training did not differentially influence the time spent on the agility test between the two types of training. Despite the times reduction in the posttest measurements in the experimental groups, no significant differences were observed between them. Specifically, the VertiMax group exhibited a significant decrease in the running times compared to the control group. Additionally, identifying the optimal rest period of approximately five minutes to maximize agility improvement adds a key element to understanding PAPE mechanisms, and supports previous research highlighting the importance of recovery time [21].

These findings support the effectiveness of variable resistance training, such as VertiMax, in enhancing agility, and are consistent with the existing literature [27, 30]. These transient adaptations may be due to increased muscular stiffness in lower limbs, created by potential energy stored in muscles and tendons, allowing a better disposition for powerful movements [1]. The results regarding agility changes in this study are not in line with the longitudinal study by McClenton et al. [14], who compared VertiMax training and depth jumps, varying an intensity of each method each week, and found significant improvements only in a group performing depth jumps.

The Bayesian analysis strengthens the conclusions of this study, emphasizing the crucial role of the rest period in the model and suggesting that including the training type is not decisive as a predictor. These results are consistent with variability observed in literature regarding relative effectiveness of different training methods for PAPE [4]. The Bayesian two-way repeated measures ANOVA was conducted to assess an alternative model (H1) indicating that one or more factors have an effect. The analyses mainly reveal a model supported by an alternative hypothesis that agility test's running time depends primarily on a rest period, with a Bayes Factor 10 (BF10) = 1. The data in the effects analysis suggest substantial support for including a rest in the model, infinitely surpassing the evidence for a model without this predictor. Moreover, there is not enough decisive evidence for an inclusion of a training type and its interaction as predictors.

Subsequently, the post hoc comparisons were conducted through the Bayesian T-Tests controlled for multiplicity. Adjusted probabilities indicate moderate evidence of the difference between the pretest and the posttest at minute two, as well as between minute two and minute five of rest. In contrast, there is strong evidence for the differences between the pretest and the posttest at minute five, with the BF10 of 49.27. However, there is insufficient evidence for the significant difference between the training groups (VertiMax and inertial).

The significant improvement in the running times, especially with VertiMax at minute five of rest, suggests a possible residual and lasting effect on agility capacity, supporting the idea that these methods may have long-term implications for training program planning. Lack of significant differences between the VertiMax and inertial groups indicates that both methods could be equally effective in improving agility, considering the multifaceted nature of this ability.

On the other hand, contrary to the findings of the present study, where the improvements in the agility test running times were not statistically significant, some studies indicate that incorporating an inertial platform into warm-up routines can lead to improvements in agility performance [22, 28]. For example, a study with swimmers found that performing four repetitions on an inertial device called Yo-yo squat during a warm-up produced greater improvement in swimmer's start performance compared to traditional lunge repetitions [17]. Another study by De Hoyo et al. [6] in soccer players found improvements in change of direction tests and other performance parameters. Although the mentioned studies on swimmers and soccer players showed positive results, it is essential to consider variety of factors that can influence agility performance. Other aspects such as technique, skill development, and overall fitness levels can contribute significantly to an athlete's agility, and it is important to assess a holistic impact of inertial platforms in the context of these broader factors. More research is needed to fully understand the effectiveness of using an inertial platform for warm-up exercises and its impact on overall agility improvement. While some evidence suggests that incorporating an inertial platform into warm-up routines may lead to improvements in agility performance, more research is needed to fully explore potential benefits and effectiveness of this approach. Some may argue that the effectiveness of inertial platforms in improving agility as an effective PAPE strategy is not fully supported by scientific evidence.

Limitations of the study and further research

It is essential to consider the study's limitations. Although the improvements in agility were identified, generalizing these results to different populations and specific sports should be done cautiously. The sample of participants in the study, although suitable for the study's objectives, may not be entirely representative of a general population. Additionally, the relatively short duration of the study limits the assessment of long-term effects of the interventions. For future research, considering broader cohorts and longer follow-up periods is recommended for a more comprehensive understanding of the results. It would be beneficial to explore effects of different loads on inertial devices and elastic resistances on VertiMax, as well as to include a variety of exercises to obtain detailed information about their effectiveness in different sports contexts. Furthermore, a study with longer rest periods would allow examination of not only an interval during which a significant performance improvement is observed, but also a point at which a decline begins (post-activation loss). Exploring multiple-set protocols in future studies is also suggested.

Conclusions

In conclusion, the study provides substantial evidence that the training with both the inertial device and VertiMax induces improvements in agility, with the latter showing more significant effects, especially with the optimal rest period of approximately five minutes. These findings have important implications for planning and execution of training programs, especially in sports that require rapid changes of direction and explosive movements. The integration of device-based training strategies for generating PAPE can be crucial in optimizing athletic performance, although ongoing research is necessary to inform practical and theoretical decisions in a field of physical conditioning.

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Conflict of Interest
The authors declare no conflict of interest.

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