Effect of variable resistance on post-activation potentiation: a systematic review

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Summary

Introduction: The Variable Resistance (VR), as well as the Post-Activation Potentiation (PAP) have been used as training methodologies to improve the explosive strength in athletes. By the moment, there is no specific knowledge of the number of investigations connecting both variables that exist in the main data bases.
Objective: The aim of this study was to find out which were the VR methods used to generate PAP between January 2011 and January 2016. The secondary aim was to visualize the stimulus intensity and the variations in the explosive strength levels recounted in every one of the studies consulted for this research.
Method: the design is a systematic revision of the studies previously published that connected VR with PAP. The systematic research included articles published since January 2011 until January 2016 in the Web of Science (WOS), Scopus, Sport Discuss, PubMed, and Medline. For the studies selection, only those articles using VR as a training methodology to generate PAP were identified.
Results: Nine articles were identified, which were stratified according to the training performed: (i) Intra-Session Variable Resistance (n = 3), (ii) Intra-Repetition Variable Resistance (n = 1), and (iii) Intra-Set Variable Resistance (n = 5). On the other hand, eight out of nine studies were focused on the lower limbs and none of them focused specifically on the upper limbs. It was also observed that all those studies showing significant variation in explosive strength worked with over 80 % 1RM.
Conclusions: There is no conclusive evidence to identify the real effect of VR over PAP, and clearly not for the upper limbs. However, there are indicators that the Intra-Set Variable Resistance can generate acute changes in the explosive strength levels working over 80 % 1RM.

Key words:
Variable resistance.
Post activation potentiation,
Explosive strength.

Efecto de la resistencia variable sobre la potenciación post activación: una revisión sistemática

Resumen

Introducción: Tanto la Resistencia Variable (RV) como la Potenciación Post Activación (PAP) han sido utilizadas como metodologías de entrenamiento para mejorar la fuerza explosiva en deportistas, pero hasta el momento no se sabe cuántas investigaciones existen en las principales bases de datos que relacionen ambas variables.
Objetivo: Investigar cuáles fueron los métodos de RV utilizados para generar PAP entre enero de 2011 y enero de 2016. El objetivo secundario fue visualizar las intensidades de estimulación y los cambios en los niveles de fuerza explosiva reportados en cada uno de los estudios consultados.
Método: El diseño corresponde a una Revisión Sistemática de los estudios previamente publicados que relacionaron la RV con PAP. La búsqueda sistemática incluyó artículos publicados desde enero de 2011 a enero de 2016 en Web of Science (WOS), Scopus, Sport Discuss, PubMed y Medline. Para la selección de los estudios, se identificaron sólo aquellos artículos que usaron RV como metodología de entrenamiento para generar PAP.
Resultados: Se identificaron nueve artículos, los cuales fueron estratificados según el entrenamiento que realizaban: (i) Resistencia variable intra-sesión (n = 3), (ii) Resistencia variable intra-repetición (n =1) y (iii) Resistencia variable intra-serie (n = 5). Por otro lado, ocho de los nueve estudios consultados estuvieron centrados en los miembros inferiores y ninguno de forma específica en los miembros superiores. También se pudo observar, que todos aquellos estudios que reportaron cambios significativos en la fuerza explosiva trabajaron sobre el 80 % de 1RM.
Conclusiones: No existe evidencia suficiente para conocer el verdadero efecto de la RV sobre la PAP, más aún en los miembros superiores. Sin embargo, hay indicios que la resistencia variable intra-serie puede generar cambios agudos en los niveles de fuerza explosiva trabajando sobre un 80 % de 1RM.

Palabras clave:
Resistencia variable.
Potenciación post activación.
Fuerza explosiva.

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Introduction

Various training methods are used to improve explosive strength levels in athletes. These methods include plyometrics[1], contrast training[2], eccentric dynamic protocols[3], isometric loads[4], electro-stimulation[5], sports training methods that incorporate Variable Resistance (VR)[6-9], among others.

In terms of sport training based on VR, it is important to mention that the main feature of these training systems is the variation or change of intensity in the work session. Over recent years, it has been shown that this stimulation method has acquired a leading role in various lines of research[9-18]. Increases in the levels of explosive strength are attributed to the activation generated in the Central Nervous System by the change of intensity in the repetition, series or work session.

Some of the possible benefits of stimulation with VR protocols could be Post-Activation Potentiation (PAP); this training method corresponds to a transitory increase of muscle strength and power following a prior motor action[19]. PAP can be achieved through diverse forms of activation, among which are maximum voluntary contractions (MVC), also called post-tetanic potentiation[20]. Therefore, PAP would produce an increase in the explosive strength of athletes[19, 20].

The logical sequence for the generation of PAP via VR has three phases: The first corresponds to the assessment of unpotentiated physical capacity. The second corresponds to the application of a stimulus that triggers the potentiation (in this phase it can be activated with VR). While in the third phase the physical capacity measured in Phase 1 is assessed again, but now in a potentiated state.

Hirayama (2014)[14], with the aim of achieving PAP in study subjects, used VR stimulation as an activation method. The researcher concluded that VR is a good alternative to acutely increase levels of explosive strength. However, there is little evidence to link the different VR methods with PAP, both for lower and upper limbs. The main aim of this systematic review was to research which were the variable resistance methods used to generate PAP between January 2011 and January 2016. As a secondary objective, the stimulation intensities were analysed, as well as changes in the explosive strength levels reported in each of the studies consulted.

Method

Literary search

To develop this systematic review, an exhaustive literary search was performed both manually and electronically. To do this, different combinations of the key words displayed in Table 1 were used. The electronic search identified articles published in the *Web of Science (WOS), Scopus, Sport Discuss, PubMed* and *Medline*.

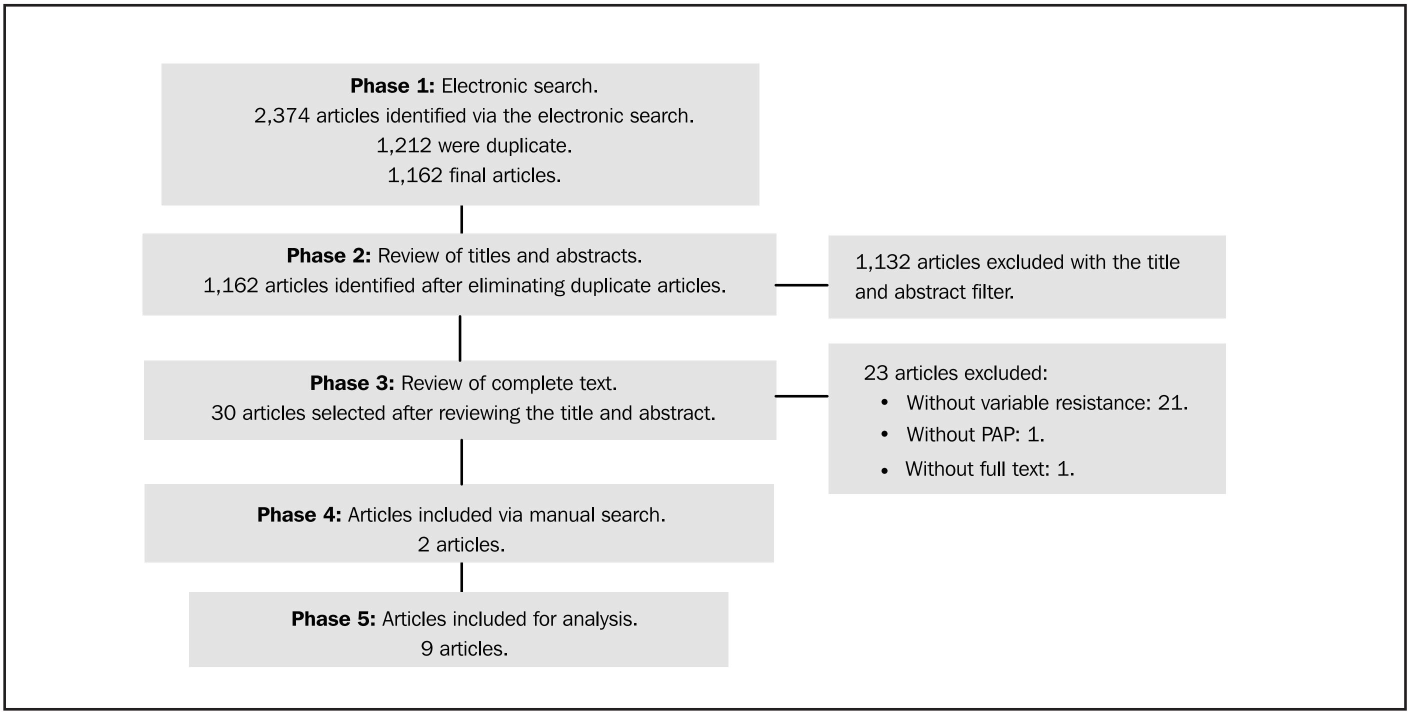
The search strategy was divided into five phases (Figure 1). The first phase was an electronic search in the different databases. All the duplicates were eliminated in this phase of the search; a total of 1,162 articles were identified for the title and abstract filter. Phase two consisted in a review of all the titles and abstracts of the articles that could be included in the review; at the end of this phase, 30 articles remained. In phase three, the complete articles were read, thus identifying the final articles to be included in the analysis. After reading the complete articles, 23 studies were eliminated, 21 as they did not use variable resistance as an activation method, one because it did not relate the variable resistance used in the study to PAP, and one given the impossible nature of achieving the complete text. Phase four consisted in adding the articles found in the manual search. The references of the articles added were reviewed with the possibility of identifying new studies. At this stage two studies were included. Furthermore, independent reviewers agreed upon the 9 articles included for analysis.

Table 1. Search strategy using a selection and combination of key words.

Steps	Strategy	WOS*	Scopus	Sport Discuss	PubMed	Medline
1	post-activation potentiation	73	39	42	36	27
2	potentiation muscle	491	1.079	21	396	340
3	activation muscle	19.078	18.512	1.166	17.821	13.838
4	#1 OR #2 OR #3	19.413	19.348	1.219	18.133	14.082
5	complex training	8.832	7.045	97	14.906	5.066
6	contrast training	4.637	3.135	40	7.688	2.995
7	strength training	8.325	8.507	2.259	10.725	6.925
8	resistance training	6.046	7.117	2.010	6.452	5.597
9	#5 OR # 6 OR #7 OR # 8	24.355	21.701	3.743	32.228	17.299
10	#4 AND #9	692	539	138	568	437

*WOS (Web of Science).

Figure 1. Identification of studies in the systematic review.



Inclusion and exclusion criteria

The search limits were: articles published in the last five years (January 2011 to January 2016), written in English, Portuguese, French or Spanish and in the field of study or other criteria regarding the database.

The importance of each study was assessed in accordance with the inclusion criteria established in Table 2. The studies that did not meet the inclusion criteria were excluded. The discrepancies found were resolved through consensus of the researchers.

Assessment of the methodological quality

The Newcastle-Ottawa Scale (NOS) was used to assess the quality of the studies. Classification was performed based on three criteria: selection (maximum four stars), comparability (maximum two stars) and results (maximum three stars). Articles graded between seven and nine were considered to be of *high* methodological quality, from four to six *moderate* and below four *low*.

Table 2. Inclusion criteria.

Study design	Experimental
Demography	Healthy adult male athletes (trained-not trained)
Intervention	Strength training that combines loads and produces reinforcement (acute or chronic)
Comparator	The increase of PAP generates an increase in strength
Results	Positive and negative

Results

Amount of results available

The search was performed electronically and manually. 2,374 articles were identified, of which 1,212 duplicates were eliminated, leaving 1,162 articles filtered for inclusion. The titles and abstracts were assessed depending on their relevance for systematic review, resulting in 30 articles. The complete texts for 29 bibliographic references were obtained. After applying the inclusion criteria to the full texts of these documents, 23 articles were excluded. After performing a manual search, two studies were included, leaving a final total of 9 articles to analyse.

In terms of the grading obtained by the articles according to the NOS, one study obtained a moderate grading whilst the remaining eight received a high quality grading, seven of these achieving the maximum quality (Table 3).

Variable resistance

Even though PAP can be generated in any muscle group[20], the application methods of VR are very wide. In this respect, the research reviewed allowed for the observation of different intervention styles

Table 3. List of articles included with grading according to the *Newcastle-Otawa Scale* (NOS).

	Selection	Comparability	Results	Total
Chiu & Salem[11]	***		***	6
Crum *et al.*[12]	****	**	***	9
Fukutani *et al.*[13]	***	*	***	7
García-Pinillos *et al.*[7]	****	**	***	9
Hirayama *et al.*[14]	****	**	***	9
Miarka *et al.*[15]	****	**	***	9
Nacleiro *et al.*[16]	****	**	***	9
Okuno *et al.*[17]	****	**	***	9
Wyland *et al.*[18]	****	**	***	9

in various sporting modes. This diversity of VR application methods to generate PAP meant that the comparison and synthesis of the results were more complex. With the aim of organising the information and meeting the aim of this review, the studies were divided into three categories based on the variable resistance methods: (i) Intra-session variable resistance (n = 3), (ii) intra-repetition variable resistance (n = 1) and (iii) intra-series variable resistance (n = 5) (Table 4).

Next, and following a thorough systematic review of the past five years, only the studies that linked some of the variable resistance methods (Intra-Session, Intra-Series, Intra-Repetition) to PAP were displayed:

Intra-session variable resistance

This kind of variable resistance consists in changing the intensity of the loads within the session, i.e. the training series should increase or reduce the intensity of the work. This training method may overlap with the *Contrast Method*, as the structure is very similar, however the central difference is that the *Contrast Method* always has heavy loads and then a motor action (physical test or sporting test), whilst the *intra-session variable resistance* method changes the intensity of the load randomly, depending on how the trainer programmes the training session. It is also important to mention that, in translations in English, the terms *"Contrast Training"* or *"Complex Training"* are used. For this reason, and so as not to make mistakes in the application of the training sessions, the precise methodology used should be identified (Figure 2).

García-Pinillo *et al*. (2014)[7], developed a 12-week training programme, in which the study used intra-session variable resistance. During the first week of intervention, the training sessions combined the isometric half squat (40-second contraction), plus jumps from a sitting position in the same session. During the second week of intervention, the training sessions combined the isometric half squat (60-second contraction), plus jumps alternating the right lower extremity and the left within the same session. In the following weeks, the isometric contraction times were varied, as were the amount of series and jumps. However, the rest time between the series was always two minutes. Upon finishing the study, the researchers reported significant changes in the explosive strength assessed via the CMJ only for the test group (p<0.001); likewise, in the same study changes were reported in the Balsom test and in the ball kicking speed test. Along the same lines of stimulation, Hirayama (2014)[14] stimulated with increasing loads using the Squat method, finishing with maximum isometric contractions in the same exercise, whilst the control parameter was the evaluation of explosive strength via the CMJ test (the assessments were performed at the end of each load). Upon finishing the study, the researchers reported changes in explosive strength from 60% of 1MR (60% of 1MR - 80% of 1MR and IMC p<0.05). In a study presented by Okuno *et al*. (2013)[17], the loads were increased within the session in the following way: 1 x 5 to 50% 1MR + 1 x 3 to 70% 1MR + 5 x 1 to 90% 1MR, whilst the control parameter was the *Repeated Sprint Ability* (RSA) test. Upon finishing the study, the researchers reported significant differences in the best time and average time in the RSA test only for the test group (p<0.01).

Intra-series variable resistance

This kind of variable resistance consists in changing the intensity of the loads within the session, i.e. during the development of the training series the intensity of the work should be increased or reduced every certain number of repetitions. This training method can be carried out

Figure 2. Example of intra-session variable resistance.

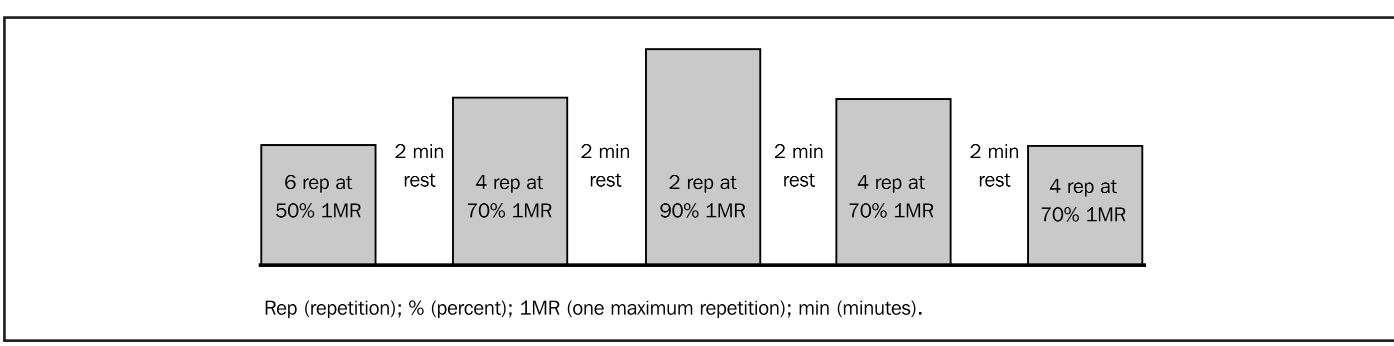
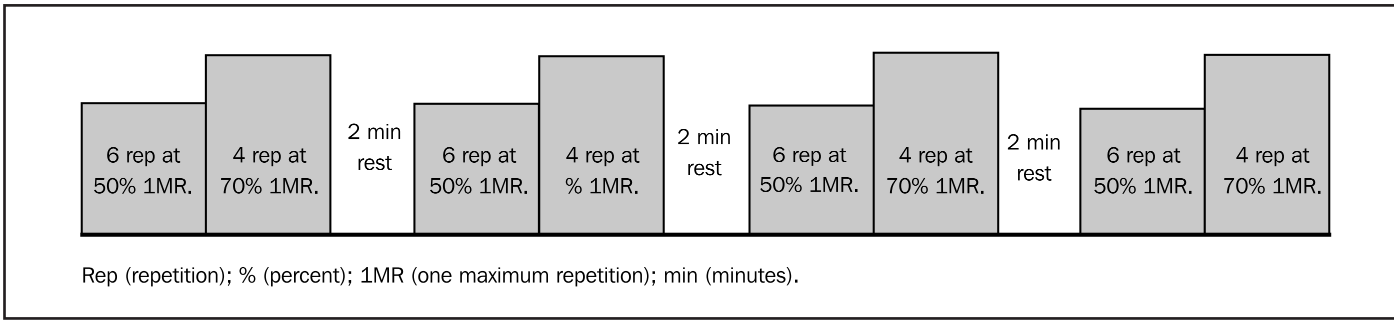


Table 4. Characteristics of the publications that relate variable resistance to PAP.

Authors	Year	Resistance type	Treatment	Results
Chiu y Salem[11]	2012	Intra-Series	a) 2 x 4 start-ups (70-80-90-100% of 1MR). Control parameters: CMJ (before, during and at the end of the session).	Significant differences (p<0.05) in CMJ from the base line and the middle measurement. Significant differences (p<0.05) in CMJ from the base line and the final measurement.
Crum, *et al*.[12]	2012	Intra-Series	a) Control. b)1 x 30- 1 x 40- 3 x 50% of 1MR in Squat. c)1 x 30- 1 x 40- 3 x 65% of 1MR in Squat. Control parameters: CMJ one minute before each condition; CMJ 0.5, 3, 5, 10 and 15 minutes of each condition.	There were no significant differen-ces in CMJ in any of the conditions (p<0.05).
Fukutani, *et al*.[32]	2104	Intra-Series	a) Weight condition: 1 x 45- 1 x 60- 3 x 75- 3 x 90% of 1MR in Squat. b) Moderate conditions: 1 x 45- 1 x 60- 3 x 75% of 1MR in Squat. Control parameters: 3CMJ before and after both conditions.	In both conditions significant increa-ses were recorded in CMJ (p>0.05).
García-Pinillos, *et al*.[7]	2014	Intra-Session	a) Isometrics + plyometrics without external loads. b) Control. Control parameters: CMJ, Speed in 5, 10, 20 and 30m, agility test and kicking speed test.	Significant changes were observed in the CMJ, Balsom test and ball kicking speed (p<0.001) were only observed in the test group. There was a significant difference for both groups in 5, 10, 20 and 30m (p<0.05).
Hirayama, *et al*.[14]	2014	Intra-Session	a) 1 x 20- 1 x 40- 1 x 60- 1 x 80% 1MR-1 CMI in ½ Squat. b) Control. Control parameters: CMJ after each execution.	Significant differences were observed in CMJ after the application of loads with: 60% of 1MR, 80% of 1MR and CMI (p<0.05).
Miarka, *et al*.[15]	2011	Intra-Series	a) Special Judo Fitness Test (SJFT). b) Plyometrics + SJFT. c) Maximum strength + SJFT d) Contrast exercise + SJFT.	Significant differences were found in the number of throws during condi-tion "b" (plyometrics) when compared to the Control (p<0.05).
Nacleiro, *et al*.[16]	2014	Intra-Series	a) 1 x 80% de 1MR in ½ Squat without vibration. b) 1 x 80% de 1MR in ½ Squat with vibration. c) Control. Control parameters: 3 CMJ and one DJ (optimum falling height).	Significant increases in CMJ after 4 min of recovery (p<0.05). Significant increases with the low volume protocol, regardless of the (p<0.015). Significant increases in DJ with the protocol.
Okuno, *et al.*[17]	2013	Intra-Session	a) 1 x 5 to 50% of 1MR + 1 x 3 to 70% of 1MR + 5x 1 to 90% of 1MR. b) Control. Control parameters: RSA test (6 x 30m).	Significant differences in the best time and average time of RSA only for the test group (p<0.01).
Wyland, *et al*.[18]	2015	Intra-Repetition	a) Control: Sit & Rest test for 5 min. b) 5 x 3 to 85% of 1MR + isometrics in Squat. c) 5 x 3 to 85% of 1MR + 30% additional load via an elastic band. Control parameter: 10-yard test (9.1m).	Significant reduction in the 9.1m test (p=0.002) at 4 min of rest.

IMC (Isometric Maximum Contraction); 1MR (One Maximum Repetition); BW (Body Weight); SJ (Squat Jump); CMJ (Counter Move Jump); AB (Abalakov); DJ (Drop Jump); SJFT (Special Judo Fitness Test).

Figure 3. Example of intra-series variable resistance.



in two ways: The first can be performed using electronic devices that enable the resistance to be varied every certain number of repetitions in a programmed way, whilst the second is manually - a method that requires trainers and/or assistants to change the load. The second action is just as precise as the use of electronic devices, but it is less efficient (Figure 3).

With regards to this form of stimulation, some authors have reported the following: Chiu and Salem (2012)[11] demonstrated significant changes in explosive strength assessed via the CMJ ($p < 0.05$). These researchers applied two series of four increasing start-up repetitions (80 - 80 - 90 - 100% of 1MR). However, Crum *et al*. (2012)[12], using two increasing Squat methods (a: 1 x 30 – 1 x 40 – 3 x 50% of 1MR in Squat. b: 1 x 30 – 1 x 40 – 3 x 65 % of 1MR in Squat), did not report significant changes in any of the conditions ($p > 0.05$).

In another research study, Fukutani *et al.* (2014)[13] applied two increasing training methods using Squats (a: 1 x 45 – 1 x 60 – 3 x 75 – 3x 90% of 1MR. b: 1 x 45 – 1 x 60 – 3 x 75% of 1MR), whilst the control parameter to assess explosive strength was the CMJ (this assessment was performed before and after applying the protocols). Upon finishing the study, the researchers reported significant increases in explosive strength with both methodologies ($p=0.05$). Another study that aimed to trigger PAP was that presented by Miarka *et al*. (2011)[15]; these researchers applied three treatments (Table 4), whilst the control parameter was a special judo fitness test (SJFT). Upon finishing the research, the authors reported a significant increase in the amount of throws following the application of a plyometric protocol ($p < 0.05$), the specific characteristic of this method was the increase in the height of the bars over the series (10 x 3 jumps 20 - 40 - 60 cm with 30s rest).

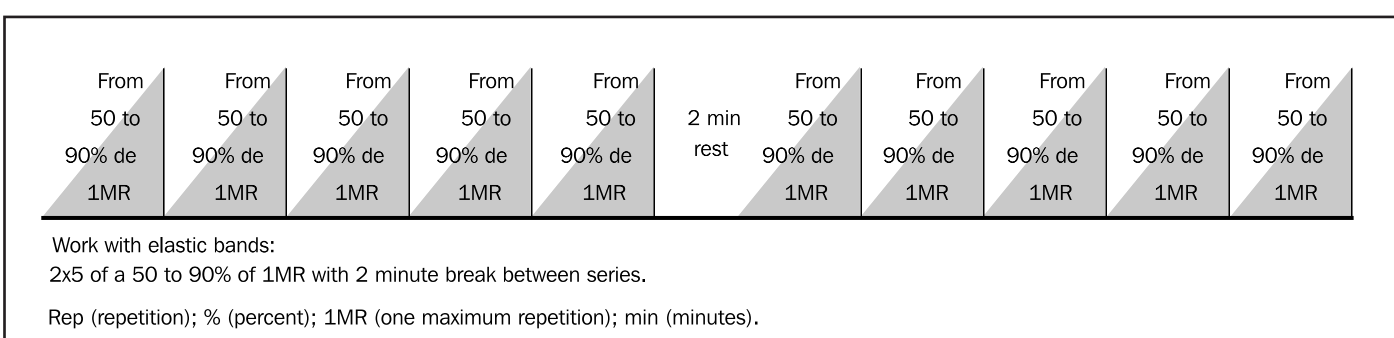
Another methodology used to trigger PAP has been to combine strength exercise with vibration. In this respect, Nacleiro *et al*. (2014)[16] compared two Squat protocols with and without vibration in the final phase of the series. These researchers used the CMJ and *Drop Jump* (DJ) as the control parameter. Upon finishing the study, the researchers reported the following: significant increases in CMJ after 4 min of recovery ($p<0.05$), significant increases in *Drop Jump* (DJ) with the vibration protocol after 1 min of recovery ($p=0.015$).

Intra-repetition variable resistance

This kind of variable resistance consists in changing the intensity of the loads within the repetition, i.e. the training repetitions should increase or reduce the intensity of the work. This training method can be carried out in three ways: with elastic bands, with chains and/or electronic devices that allow the resistance to be varied in a programmed and precise way (Figure 4).

Also, in the PAP search, overloads were used with elastic bands. In this respect, Wyland *et al.* (2015)[18] applied three experimental conditions. The first, defined as "control", consisted in the application of the Sit &

Figure 4. Example of intra-repetition variable resistance.



Rest test for 5 min. The second protocol had 5 series of 3 repetitions at 85% of 1MR plus an isometric load. The third treatment included 5 series of 3 repetitions at 85% of 1MR with an additional load of 30% via an elastic band. The control parameter was the 10-yard test (9.1m). Upon finishing the study, the researchers reported a significant reduction in the 10-yard test (p=0.002) after 4 min of rest.

Discussion

Type of variable resistance: the main aim of this review was to research the variable resistance methods used to generate PAP. With regards to this objective, it was observed that the vast majority of the articles found stimulated intra-series variable resistance to generate PAP[11-13,15,16]; secondly, intra-session variable resistance training session were discovered[7,14,17]; and finally, intra-repetition variable resistance treatments were found in one study18. Despite the treatments that relate VR with PAP being divisible into three categories, the amount of existing studies in the majority of databases is low. This low number of studies is possibly due to the complexity of both variables. The aforementioned has been particularly notable over the past five years - the period in which serious scientific studies that address these training methods have been developed. To this it should be added that varying resistances, whether in the session, in the series and/or in the repetition, is not very effective, requires time, creates poorly controlled rests or considerably increases costs. This last point refers to the use of electronic devices that modify loads automatically.

Study duration: in seven of the nine studies consulted, the acute effect of VR on explosive strength was established, i.e. if the activation methods based on VR lead to PAP in the study participants within the training session. The remaining two studies focused on the chronic effects, i.e. long-term neuromuscular adaptations caused by the VR[7,16]. It is also important to analyse that once the systematic review has been performed no research studies relating VR with PAP were found for the upper limbs. Therefore, and regardless of the VR methods used, this is one of the alternative methodologies for future studies seeking to develop explosive strength. The aforementioned is due to the fact that in all the sporting activities observed, the lower extremities are largely those responsible for sporting performance, just as PAP was looked for in footballers[7], weight-lifters[13], weight lifters[14], judo players[15], athletes[16] and handball players[17]. In these sports, even more so in those that are defined by the body weight of the subjects, increases in muscle power levels must be achieved without considerably increasing muscle mass; for this reason, the movements should be executed with as much speed as possible, thus the athletes will be able to recruit type II fibres based on the speed of movement[21,22].

Stimulation intensities: with regards to the secondary aim of this review, it could be observed that all the treatments that used intensities of around 75% of 1MR obtained significant increases in explosive strength[11,12,16]. The aforementioned is based on the recruitment of type II fibres, as these kinds of fibres are the most likely to generate PAP[22]. Conversely, in studies that used intensities lower than 70% of 1MR, no increases were seen in explosive strength[12]. This last kind of stimuli have two favourable conditions for generating PAP; on the one hand, low intensity helps dissipate fatigue quicker, and on the other hand, it also enables the recruitment of type II fibres, whenever the movement speeds are high.

In accordance with the literary review performed, there are no intra-series variable resistance protocols in power zones (0.6 to 0.9 m/s of vertical bar speed)[23] that trigger PAP and that have made significant changes to explosive strength. As a result of the aforementioned, there is a need to understand the behaviour of explosive strength in power zones, and how this strength increases as a result of PAP of the muscles involved in the movement.

Conclusions

- VR is a field with little scientific evidence in terms of experimental works to generate PAP acutely in sporting performance.
- There are indications that VR training triggers PAP acutely in the lower limbs, whilst research on the upper limbs is practically non-existent.
- Therefore, more research is required in the relevance that VR has in sporting performance.

Practical applications

From a practical point of view, working with *variable resistance* is a good alternative to increase explosive strength levels in the lower extremities, though the following aspects should be taken into consideration:

- To trigger PAP in sports with predominant explosive strength, loads of around 80% of 1MR should be stimulated, in order to stimulate Type II Fibres.
- If the aim is to work with *intra-repetition variable resistance exercises* to trigger PAP, there should be some kind of device available that enables the precise quantification of the training load, as the use of elastic bands and/or chains makes it harder to control the training intensity.
- If devices that control and/or quantify the training intensities are not available, it is advisable to use *intra-series variable resistance exercises,* or *intra-session variable resistance exercises,* as these kinds of stimuli are easier to control.
- Finally, researchers and trainers are encouraged to continue to try out VR protocols, preferably in power zones (0.6 to 0.9m/s of vertical bar velocity).

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