The Effect of Loading on the Enhancement of Counter Movement Jumps (CMJ) over Three Consecutive Trials

by

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We accept this thesis as conforming to the required standard

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Abstract

The purpose of this study was to investigate the acute effects on six dependent variables of neuromuscular activation through maximal voluntary isometric contractions (MVIC) performed in the squat position. The MVIC's were performed at a knee joint angle of 100 degrees and held for 7 seconds. The six dependent variables were vertical jump height (VJH), peak force (PF), rate to peak force (RPF), peak power (PP), peak acceleration (PA) and peak velocity (PV). Furthermore, correlations were performed between relative and absolute strength and the six performance measurements. Sixteen trained males (age: $\overline{X} = 23.06$, SD = 2.70; weight: $\overline{X} = 84$ kg, SD = 7.86) experienced with back squats participated in the study. Each subject took part in one familiarization session and two testing protocols. The familiarization session was designed to determine if learning effects were present with respect to the six performance measurements and the MVIC. Both testing protocols consisted of 4 sets of 5 countermovement jumps (CMJ) performed with 8-min intervals. The single difference between the two protocols was the execution of a 7-s MVIC performed 4 minutes prior to the execution of CMJ in protocol 1. A repeated-measures MANOVA was performed. Application of the Bonferroni procedure indicated that no significant differences occurred between protocol 1 and 2, nor did significance occur linearly across the four sets of CMJ. Only one significant correlation between relative strength and performance enhancement or absolute strength and performance enhancement was found. A significant correlation existed between absolute strength (MVIC) and PA using mean values ($p< 0.01$). No significant correlations were found with respect to absolute strength and maximal values nor were

any significant correlations found with respect to relative strength and either mean or maximal post MVIC values.

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Acknowledgments

I would like to thank my supervisor Dr. David Docherty for all his help over the last two years. I would also like to thank Dr. John Anderson and Dr. Howie Wenger for their help with my study. Thank you also to Dr. Lynneth Wolski for serving as my external examiner and thank you to Quan Tran and Tyler Goodale for their support and friendship.

Dedication

I would like to dedicate my thesis to my father and Julia. Thanks for your help and support.

Introduction

Power is defined as the product of force and velocity and is considered integral to the achievement of peak performance in a wide variety of sports (Bompa, 1994). Complex training is one of a number of training methods that attempts to develop power. Complex training involves the coupling of a resistance training exercise with a biomechanically similar plyometric exercise referred to as "complex pairs". The pair of the resistance and plyometric exercise are typically performed over repeated trials. This method of training has been postulated as a superior method for developing power and has gained considerable popularity over the last ten years (Adams, O'Shea, O'Shea & Climstein, 1992; Chu, 1996; Ebben & Watts, 1998; Güillich & Schmidtbleicher, 1996; Lyttle, Wilson & Ostrowski, 1996; Verkhoshansky & Tatyan, 1973; Young, Jenner & Griffiths, 1998). However, scientific evidence to support this claim is limited. In order to provide evidence to support the position that complex training is a method superior to either resistance or plyometric training alone with respect to producing power, further scientific study is necessary.

Complex training attempts to capitalize on the phenomenon of postactivation potentiation (PAP). PAP refers to intense loading of the nervous and muscular systems, eliciting an "excited" or "sensitive" state by which power activities may be enhanced. In complex training the intense loading in the resistance phase of the complex pair is thought to elicit the phenomenon of PAP which can then (theoretically) be used in the subsequent plyometric phase of the complex pair. Evidence for the existence of PAP has been provided through a number of studies (Gossen & Sale, 2000; Güillich &

Schmidtbleicher, 1996; Hamada, Sale & McDougall, 2000; Hamada, Sale, McDougall & Tarnopolsky, 2000; Young, Jenner & Griffiths, 1998). Studies have also been conducted in which the existence of PAP was not established. Both Hrysomalis and Kidgell (2001) and Gossen and Sale (2000) performed studies in which power activities were not enhanced by a resistive exercise executed prior to performance of the power activity. Hrysomallis and Kidgell (2001) conducted their study on the upper body and suggested that the requirements for power enhancement with respect to the upper body may differ from those of the lower body. Gossen and Sale (2000) reasoned that significant differences were not found in their study on the lower body due to an inadequate rest interval between the stimulus and the performance activity.

Assuming the existence of PAP, questions still remain regarding how best to evoke PAP in a practical setting and how best to capitalize on it. Although mechanisms contributing to PAP are undetermined (Gossen & Sale, 2000; Güillich & Schmidtbleicher, 1996; Hamada, Sale & McDougall, 2000; Hamada, Sale, McDougall & Tarnopolsky, 2000) it has been suggested that PAP is a result of neural stimulation. It has also been hypothesized that there is a mechanism that contributes to the phenomenon of PAP occurring at the muscular level (Gossen & Sale, 2000; Hamada, Sale & McDougall, 2000; Hamada, Sale, McDougall & Tarnopolsky, 2000; Sale, 2002). Phosphorylation of the myosin light chain (MLC) is accompanied by a higher sensitivity to calcium at the myosin-actin binding sites, which may in part be responsible for PAP (Hamada, Sale & McDougall, 2000; Hamada, Sale, McDougall & Tarnopolsky, 2000; Sale, 2002).

Both Güillich and Schmidtbleicher (1996) and Young et al. (1998) found increases in the performance of power activities following high-intensity loading.

Güllich and Schmidtbleicher (1996) loaded participants using 3-5 unilateral leg-press maximal voluntary isometric contractions (MVIC). Following this loading of the neuromuscular system, subjects performed countermovement jumps (CMJ) and depth jumps (DJ) on a Kistler dynamometric platform. The mean of eight jumps was calculated for the sets of jumps pre- and post-loading. They found that following three independent MVICs the participants jumped on average 3.3% higher than in the set of jumps prior to the loading. These results represented a significant mean improvement in vertical jump height ($p<0.001$). Young et al. (1998) found a significant improvement (2.8%) in vertical jump height in a set of jumps post versus pre loading. The investigators preceded a five repetition-maximum (5-RM) half-squat with a set of five loaded countermovement jumps (LCMJ). Another set of five LCMJ was performed 4 minutes after loading. Vertical jump height attained in the set of jumps following the 5-RM half-squat was statistically greater than that attained in the set of jumps preceding the 5-RM squat ($p<0.05$). Young et al. (1998) attempted to control for any combined effect from both the 5-RM squat and the LCMJ-pre on the final LCMJ-post by incorporating a set of LCMJ before the LCMJ-pre into the experimental design. They found no significant difference in vertical jump height between the first two sets of LCMJ. However, potential ordering effects cannot be completely ruled out in this study. For a more complete review of the literature, see Appendix A.

The existence of PAP has been documented in single-set studies and at the same time complex training has been suggested as a superior method for developing power. Complex training typically involves the execution of complex pairs over repeated trials. However, PAP and its effects have not been measured in a study mimicking the complex training method in which three sets of complex pairs are performed in a single training session. In order to determine if the complex training method efficiently capitalizes on the mechanism of PAP, this study examined the effects of loading on the plyometric phase over consecutive sets.

Statement of the Problem

Complex training typically involves the execution of 3-4 sets of a given complex pair targeting a muscle group (Chu, 1996; Ebben & Watts, 1998). Intense preloading is executed in the first half of each of these sets. Some studies have shown that intense loading of the nervous and muscular systems in the first phase of the first set will elicit PAP and allow for enhancement of power activities in the subsequent plyometric phase of that complex set. The second complex set also begins with intense loading, as do all subsequent sets. However, the effect of this intense loading prior to the execution of the subsequent plyometric exercises has not been examined. Coupled with PAP is fatigue and this relationship is key to the efficacy of complex training. Complex training is performed over multiple sets, and research involving multi-set studies is necessary in order to examine the efficacy of complex training as a possible means for developing power.

Statement of the Purpose

The purpose of this study was to investigate the effect of a 7-s MVIC on explosive power, as measured by 5 countermovement jumps (CMJ), over three consecutive sets of complex pairs.

Research Questions

1. Are there differences in performance in the plyometric exercise (CMJ) of a

complex pair over a series of three sets of complex pairs? In particular, are there differences in:

the mean and maximal vertical jump height (VJH);

the mean and maximal peak force (PF) generated;

the mean and maximal rate of peak force (RPF) development;

the mean and maximal peak velocity (PV) generated;

the mean and maximal peak power (PP) generated;

the mean and maximal peak acceleration (PA) generated?

2. Are there differences in performance of CMJ over a series of three consecutive sets of CMJ? In particular, are there differences in:

the mean and maximal VJH;

the mean and maximal PF generated;

the mean and maximal RPF development;

the mean and maximal PV generated;

the mean and maximal PP generated;

the mean and maximal peak acceleration PA generated?

3. Are there differences in performance of CMJ following a 7-s MVIC compared to that in the absence of a 7-s MVIC? In particular, are there differences in:

the mean and maximal VJH;

the mean and maximal PF generated;

the mean and maximal RPF development;

the mean and maximal PV generated;

the mean and maximal PP generated;

the mean and maximal peak acceleration PA generated?

Operational Definitions

1. Trained athlete: athlete who had performed resistance training a minimum of three times a week over a minimum of the last twelve months, including a minimum of one year's experience with the squat exercise.

2. Complex training: the performance of pairs of biomechanically similar exercises executed in succession as a single set (Ebben & Watts, 1998).

3. Seven-second maximal voluntary isometric contraction (7-s MVIC): Using an apparatus developed at the University of Victoria Sport and Fitness testing Centre (see Appendix B) a 7-s isometric contraction was performed. The contraction was executed in the squat position, using a 100-degree knee angle. An attempt to elicit maximal effort was made.

4. Countermovement jump (CMJ): a countermovement jump performed from a Kistler multicomponent force plate Type 9286A (KFP).

5. Complex pair: a 7-s MVIC, at 100-degree knee angle, targeting the muscles involved in vertical jumping, followed by a set of 5 CMJ.

6. Vertical jump height (VJH): the height jumped in the vertical plane as calculated by the KFP. The calculation involves an equation utilizing ground reaction force in the vertical plane, body weight and time.

7. Peak force (PF): measured by ground reaction force and displacement measurements through the KFP. PF is only concerned with force generated in the vertical plane.

8. Rate of peak force development (RPF): the peak force generated divided by the time taken to attain that force, as measured by the KFP.

9. Peak velocity (PV): the peak velocity attained in CMJ as calculated by force and displacement measurements in the KFP.

10. Peak power (PP): the maximal power attained in CMJ as calculated by force and displacement measurements in the KFP.

11. Peak acceleration (PA): the peak acceleration attained in CMJ as calculated by force and displacement measurements in the KFP.

Limitations and Delimitations

1. A7-s MVIC was used to elicit PAP.
2. Participants were trained.
3. Participants were male.
4. Participants were university-age.
5. The mean of 5 CMJ was used to calculate VJH, PF, RPF, PV, PP and PA.
6. A 4-m rest interval (RI) was used within complex pairs as a recovery period.
7. A 4-m rest interval (RI) was used between complex pairs as a recovery period.
8. Countermovement jumps were used as a representation of power.
9. The complex training testing session consisted of three sets.

Assumptions

1. Maximal effort was elicited from all participants.

2. The mental and physical condition of all participants during both testing protocols was satisfactory.

3.The UVic MVIC apparatus effectively preloaded the muscle groups recruited in CMJ and produced PAP.

4. Activation of muscle groups in MVIC reflected the activation of muscle groups during a dynamic resistance training exercise (CMJ).

5. CMJ were representative of a plyometric exercise.

6. A 7-s MVIC was a sufficient preload to stimulate the nervous and muscular systems and consequently elicit PAP.

7. The 7-s MVIC and CMJ were performed in the vertical plane.

8. Changes in the dependent variables (VJH, PF, RPF, PV, PP and PA) were a result of the 7-s MVIC.

9. The Kistler multicomponent force plate Type 9286A gave accurate readings for VJH, PF, RPF, PV, PP and PA.

10. The dependent variables (VHJ, PF, RPF, PV, PP and PA) were valid measurements of power.

11. A 4-m RI allowed for recovery from fatigue.

Methodology

Subjects

Twenty-one trained, university-age males volunteered to participate in the study. However due to attrition as a result of factors unrelated to the present study data from only sixteen subjects was used. Informed consent was obtained from all subjects using a document regulated by the University of Victoria Human Ethics Review Board (see Appendix C). All subjects were briefed on the testing protocols, equipment and the nature of the study prior to signing the informed consent. All participants were asked to refrain from any lower body training in the 72 hours prior to each training session. The subjects were randomly assigned to perform either protocol 1 or protocol 2 first.

Experimental Design

The main purpose of this study was to perform a within-subject comparison of the effects of a 7-s MVIC (7s-MVIC) on subsequent power activities. The dependent variables were VJH, PF, RPF, PV, PP and PA. The Multicomponent Kistler Force Plate 9286AA was used to measure the DVs (see Appendix D) (McBride, Triplett-McBride, Davie & Newton, 2002). The independent variable was the 7s-MVIC preload condition compared to the condition without a 7s-MVIC preload. Subjects were randomly assigned to either Group A or Group B. Group A performed testing protocol 1 (preloading) one week prior to performing testing protocol 2 (no preloading). Group B performed testing protocol 2 one week prior to performing testing protocol 1. Subjects were compared to themselves in a within-group analysis.

Experimental procedures

Familiarization Session

All subjects participated in a familiarization session. The purpose of the session was to familiarize subjects with the execution of both the 7s MVIC and CMJ, to explain the warm-up procedure and to determine MVIC reliability. All voluntary contractions and CMJ were executed on the KFP. The standardized warm-up consisted of 5 min of cycling followed by 5 min of dynamic stretching. It has been suggested that dynamic stretching, unlike static stretching, is not detrimental to subsequent power performance (Young & Behm, 2003). Stretching emphasized lower-body muscle groups and the lumbar region. Subjects then executed a set of 5 sub-maximal CMJ followed by a 7s sub maximal (70-80%) voluntary isometric contraction and then a set of 5 maximal CMJ. The sub-maximal voluntary isometric contraction (SVIC) was self-determined by each subject in the familiarization session. It was calculated as a percentage of the determined true MVIC (see below) in the testing sessions. Four-min rest intervals (RI) were provided between these three exercises.

Subjects were instructed on the execution of CMJ and then asked to perform 3 sets of CMJ on the KFP. Emphasis was placed on maximizing explosiveness. The CMJ were performed 4 minutes post-MVIC. Another 4-m rest interval was provided post-CMJ, prior to execution of the next MVIC. Subjects performed self-paced passive rest during the rest intervals. The familiarization session is graphically depicted in Figure 1.

Testing Sessions

Subjects performed the standardized warm-up before both testing sessions. Execution of the submaximal voluntary isometric contraction (SVIC) was omitted from

Data were analyzed using a repeated-measures multivariate analysis of variance (MANOVA). A significant F-ratio was realized in the MANOVA, and therefore univariate analysis was performed on group means and maximums of VJH, PF, RPF, PV, PP and PA for both testing protocols. A probability of <0.05 was considered significant.

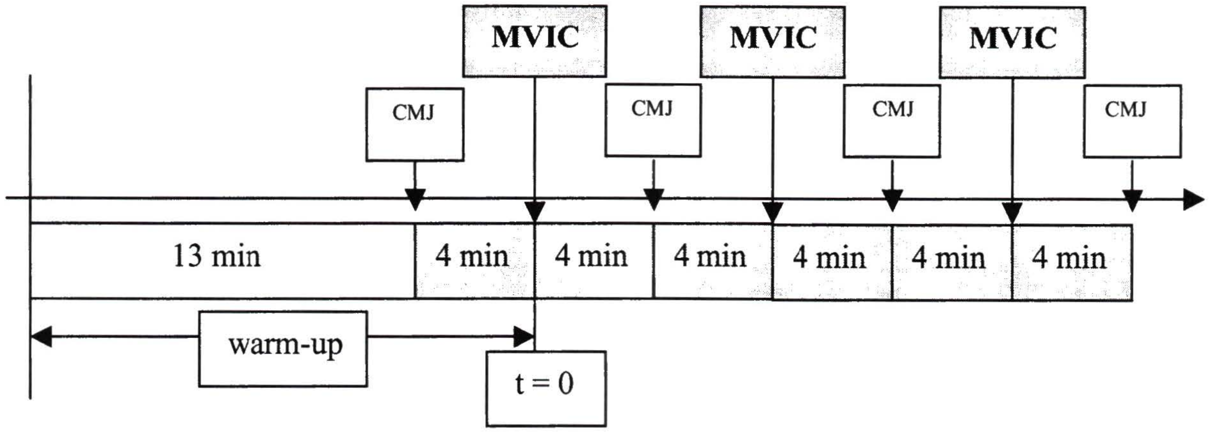

Figure 2. Time schedule for testing protocol 1.

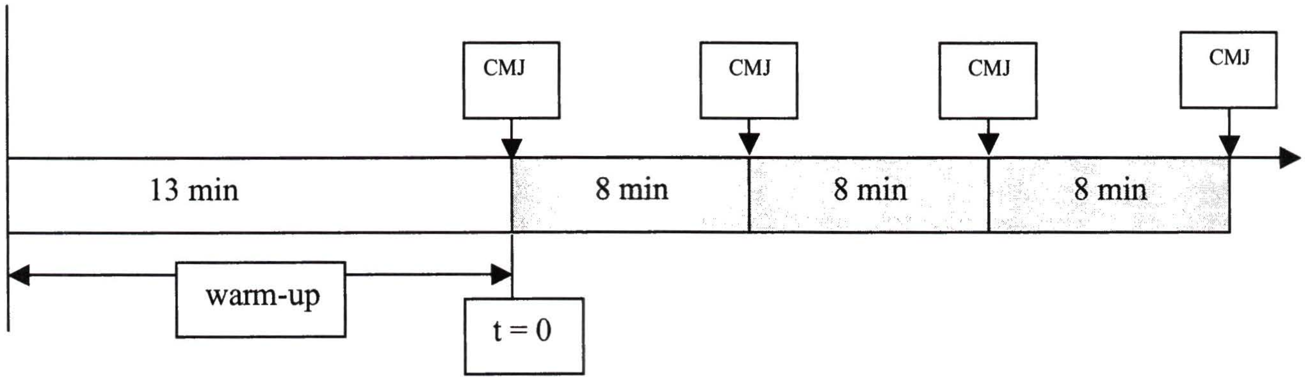

Figure 3. Time schedule for testing protocol 2.

In order to determine each participant's 7-s MVIC, three separate 7s MVICs were performed on the KFP. Adequate rest was provided between contractions in order to allow for recovery from fatigue. Knee angle was set at 100^0. A MVIC reliability measurement was performed ($F = 1.59$; $R = 0.984$). In order to control for learning effects, a baseline value was established for the six dependent variables. Three separate sets of 5 CMJ were performed on the KFP. Adequate rest was provided between contractions in order to allow for recovery from fatigue. Knee angle was set at 100^0. Reliability measurements for VJH, PP, PA, PF, RPF and PV produced non-significant F values (3.92, 3.86, 2.89, 3.04, 2.38 and 1.76, respectively) and intraclass correlation coefficients of 0.963, 0.781, 0.981, 0.803, 0.798 and 0.915, respectfully.

Results

A total of 16 subjects took part in one familiarization and two testing sessions. Testing session 1 measured both mean and maximal values for VJH, PF, RPF, PV, PP and PA over four sets of CMJ post-MVIC. Testing session 2 measured both mean and maximal values for VJH, PF, RPF, PV, PP and PA over four sets of CMJ without a MVIC. The mean 7-s MVIC for the subjects was 1368.22 N (SD 169.37). Independent analysis of testing protocols 1 and 2 found no significant enhancement of performance, and in fact a significant decrease was found in maximal PP in protocol 2 ($p< 0.01$). No significant differences were found between the two testing protocols. The only significant correlation found was between absolute strength and mean PA ($p< 0.01$).

No significant effect was observed across trial 1 and 2 for mean VJH (F= 0.184; p> 0.01) (Fig. 4).

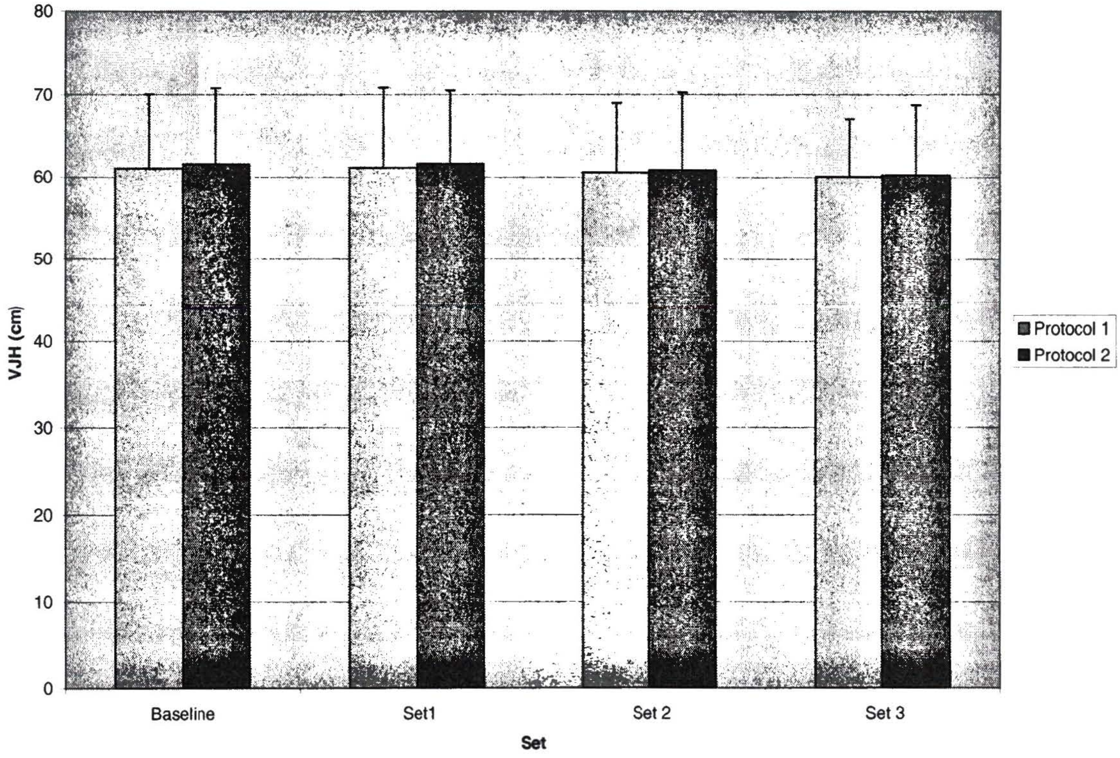

Figure 4. Mean (SD) vertical jump height (cm) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Mean (SD) VJH (cm) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for mean PP (F= 5.128; p> 0.01) (Fig. 5).

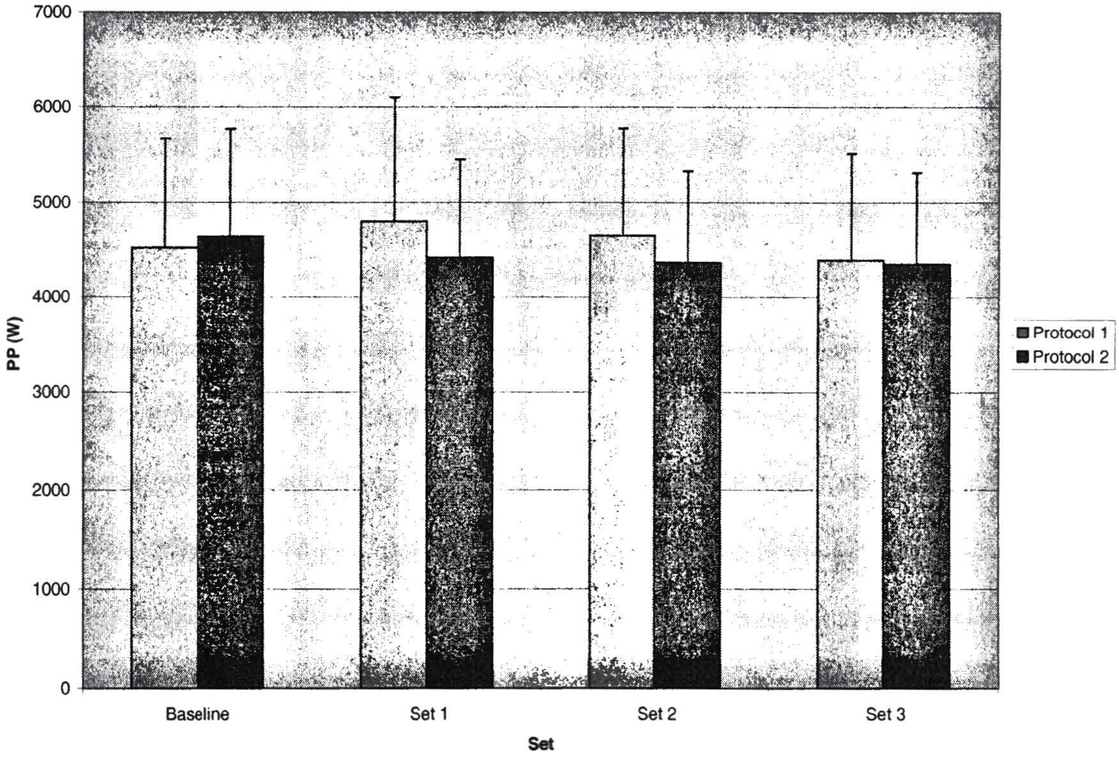

Figure 5. Mean (SD) peak power (W) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Mean (SD) PP (W) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for mean PA (F= 1.074; p> 0.01) (Fig. 6).

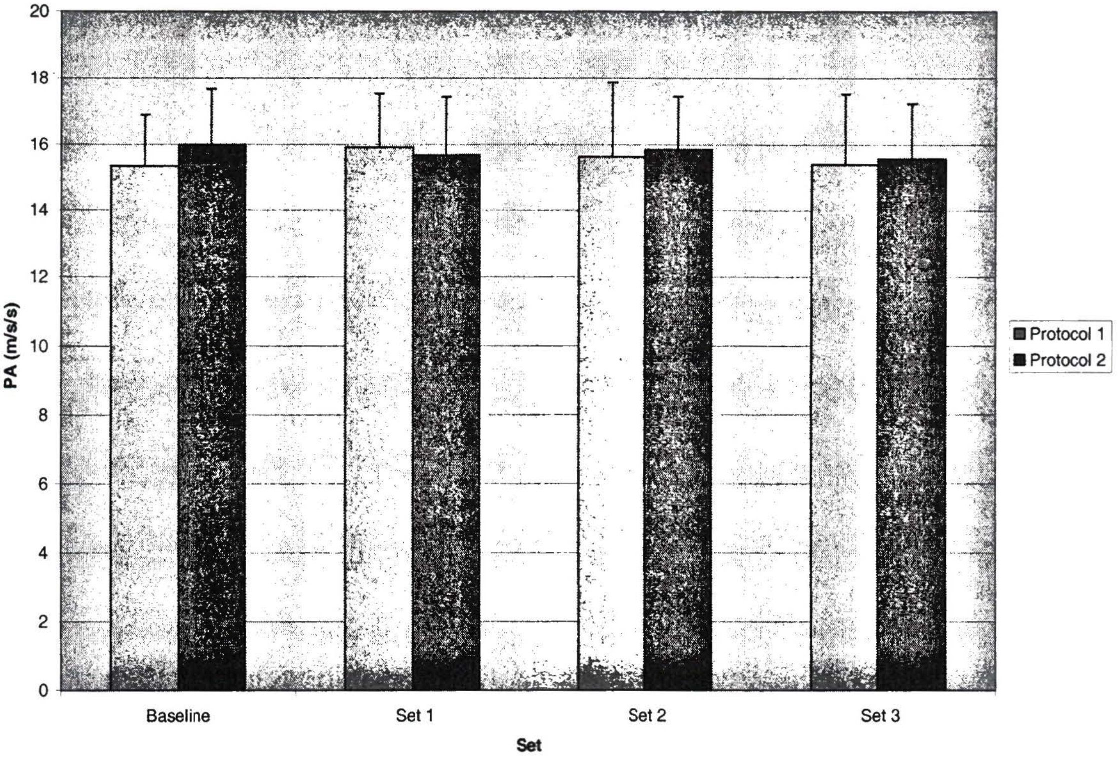

Figure 6. Mean (SD) peak acceleration (m/s/s) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Mean (SD) PA (m/s/s) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for mean PF (F= 1.800; p> 0.01). (Fig. 7).

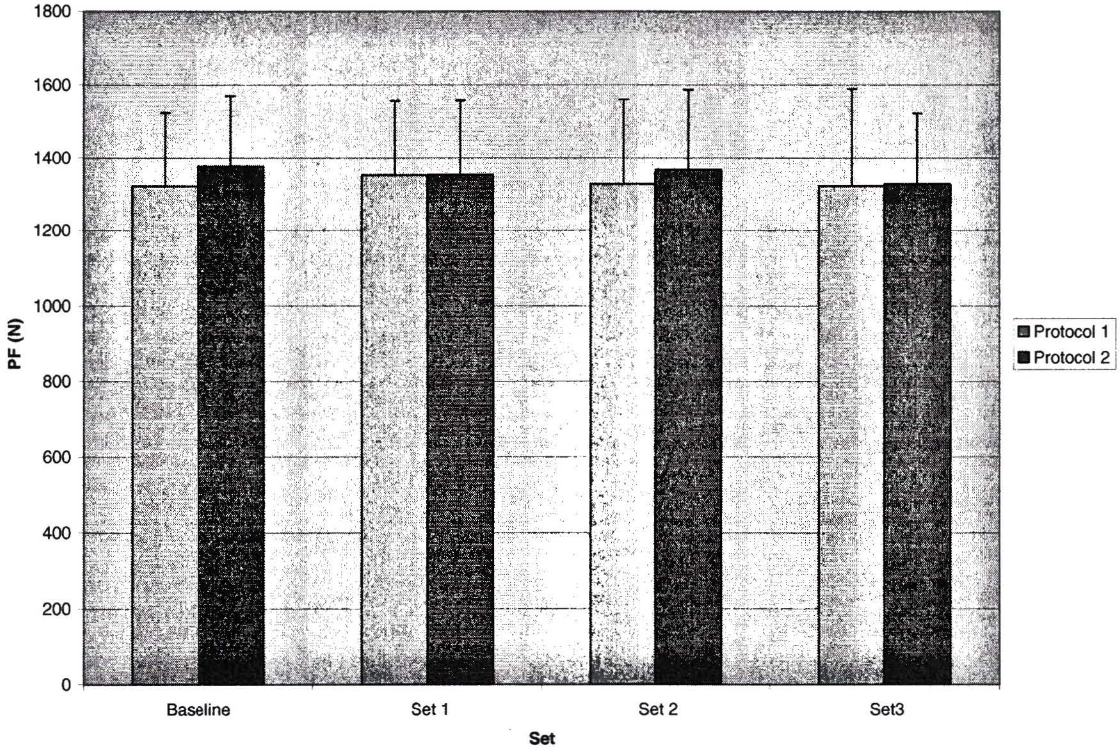

Figure 7. Mean (SD) peak force (N) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Mean (SD) PF (N) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for mean RPF (F= 3.513; p> 0.01). (Fig. 8).

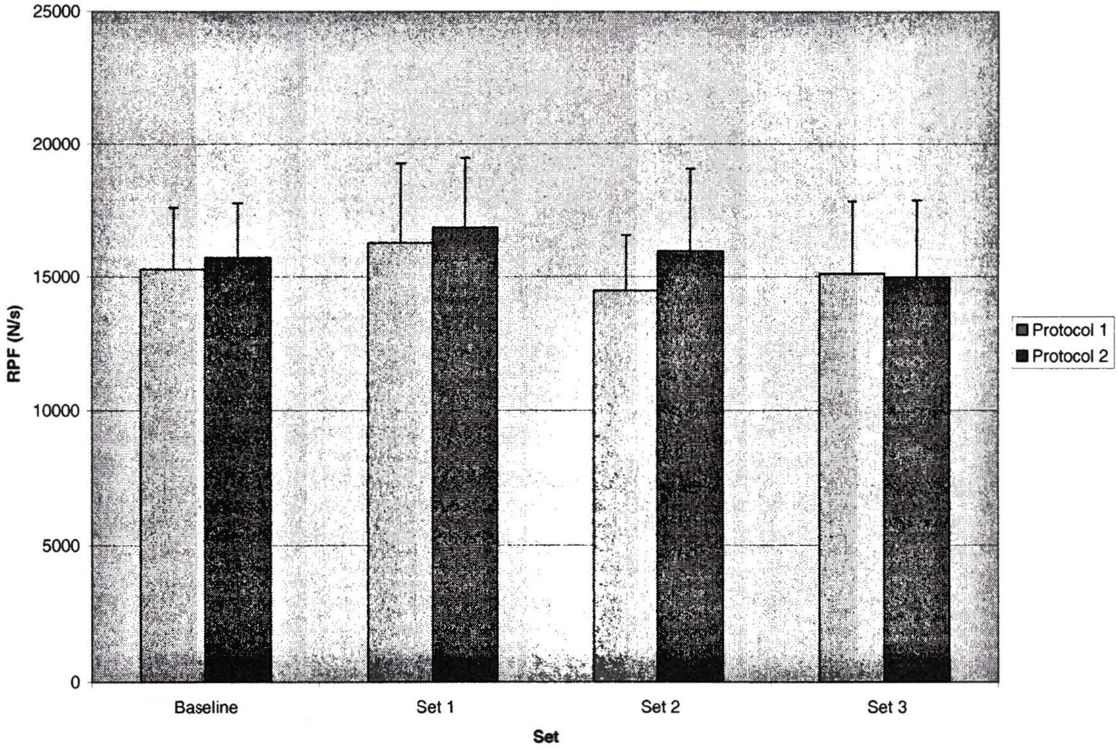

Figure 8. Mean (SD) rate to peak force (N/s) for four sets of CMJ (five jumps for each set). In each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Mean (SD) RPF (N/s) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for mean PV (F= 2.424; p> 0.01). (Fig. 9).

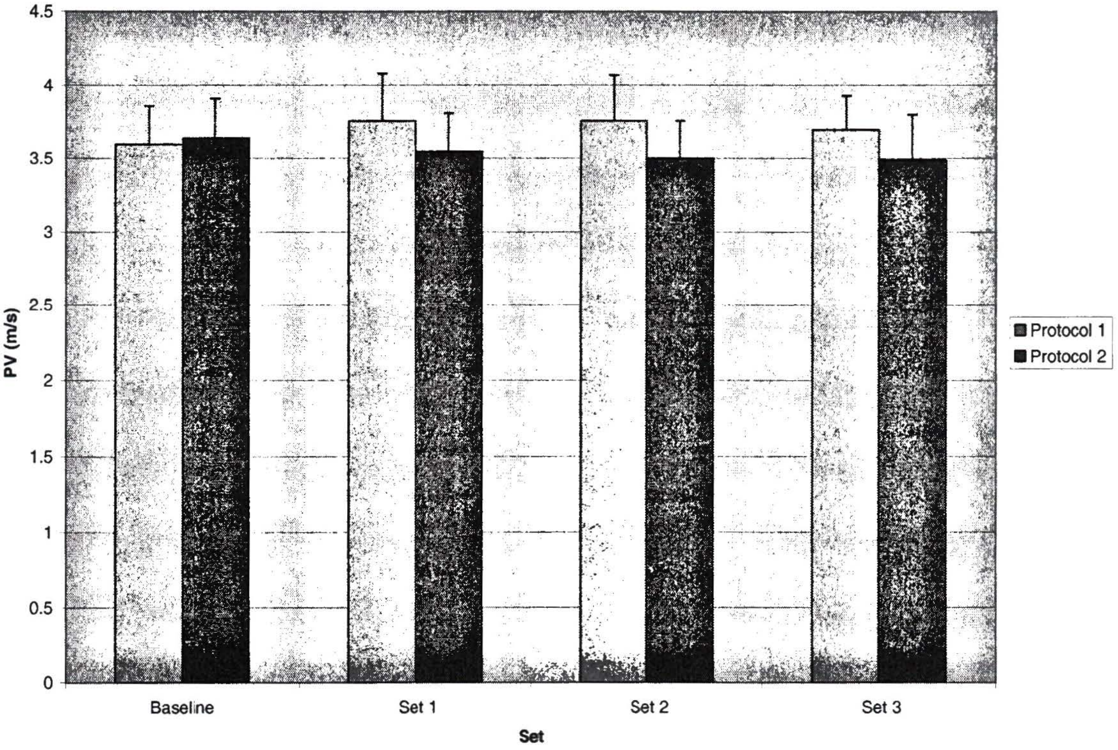

Figure 9. Mean (SD) peak velocity (m/s) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Mean (SD) PV (m/s) for four sets of CMJ (five jumps for each set). In protocol2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for maximal VJH (F= 0.262; p> 0.01) (Fig. 10).

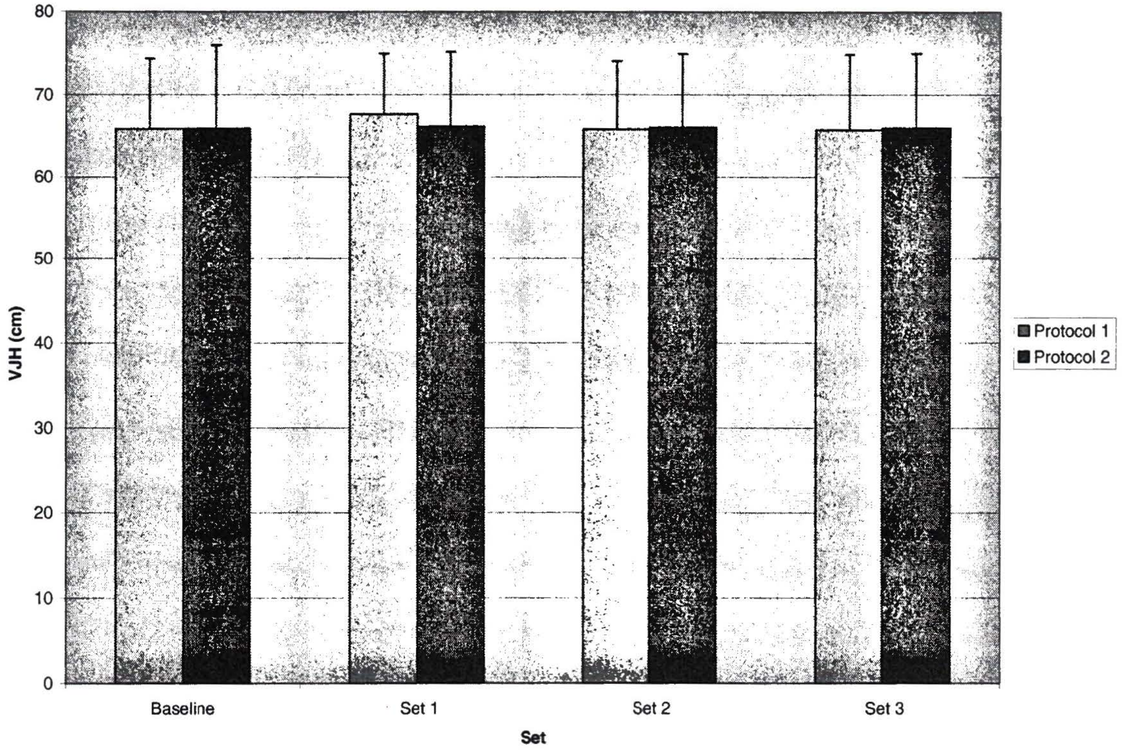

Figure 10. Maximal (SD) vertical jump height (cm) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Maximal (SD) VJH (cm) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for maximal PP (F= 1.310; p> 0.01) (Fig. 11).

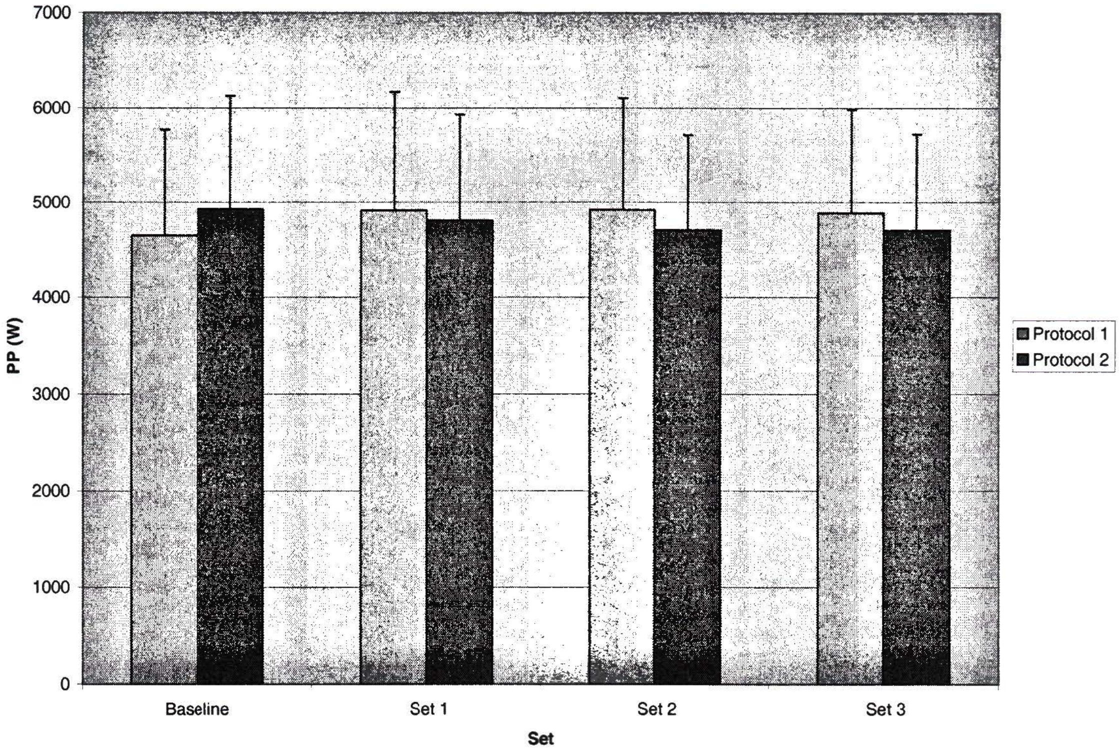

Figure 11. Maximal (SD) peak power (W) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Maximal (SD) PP (W) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for maximal PA (F= 6.236; p> 0.01) (Fig. 12).

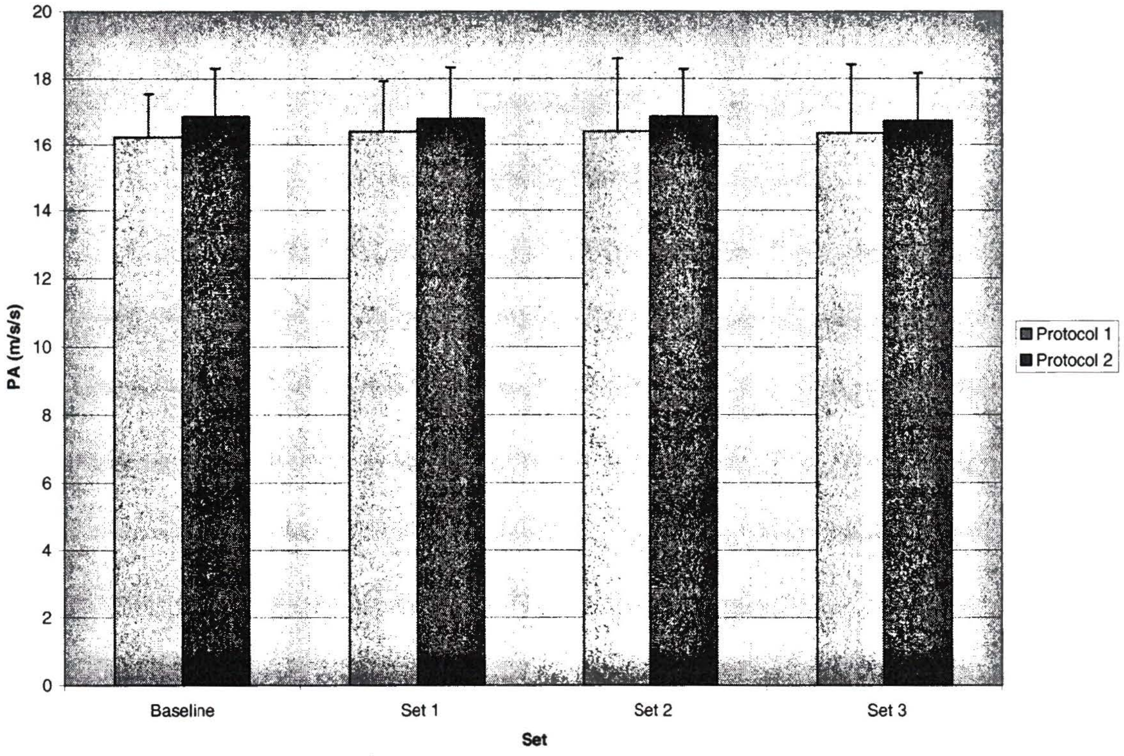

Figure 12. Maximal (SD) peak acceleration (m/s/s) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Maximal (SD) PA (m/s/s) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for maximal PF (F= 6.006; p> 0.01) (Fig. 13).

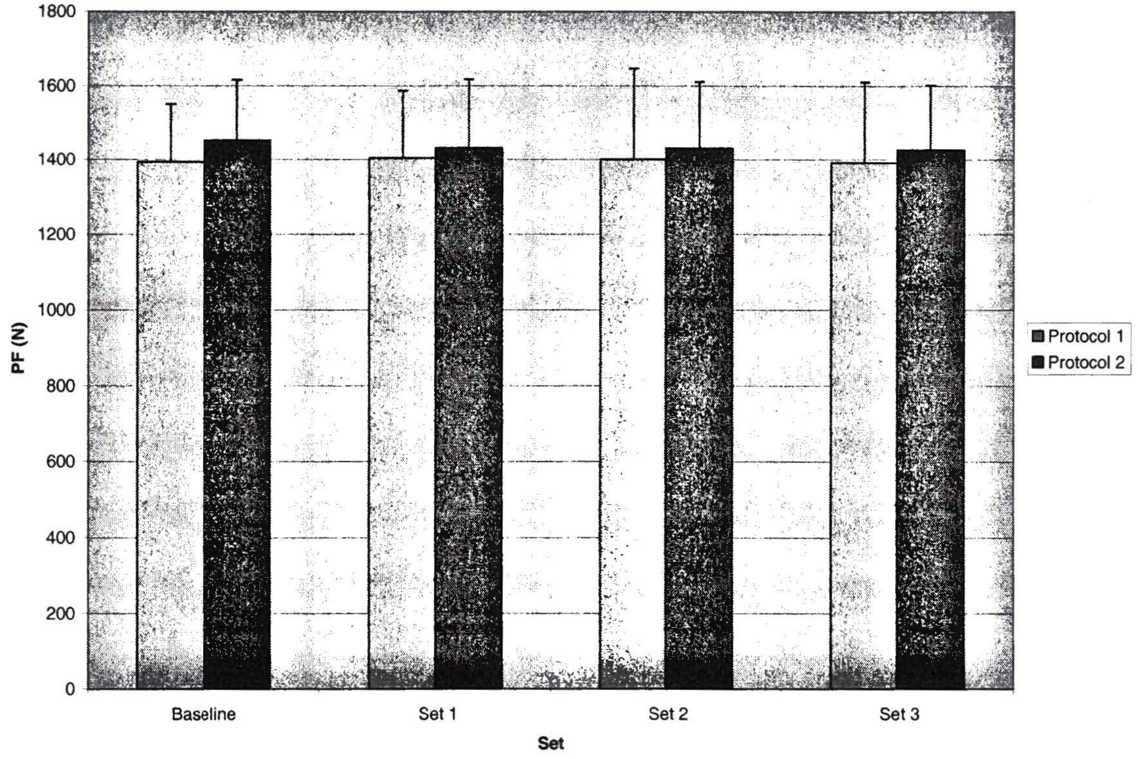

Figure 13. Maximal (SD) peak force (N) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Maximal (SD) PF (N) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for maximal RPF (F= 1.181; p> 0.01) (Fig. 14).

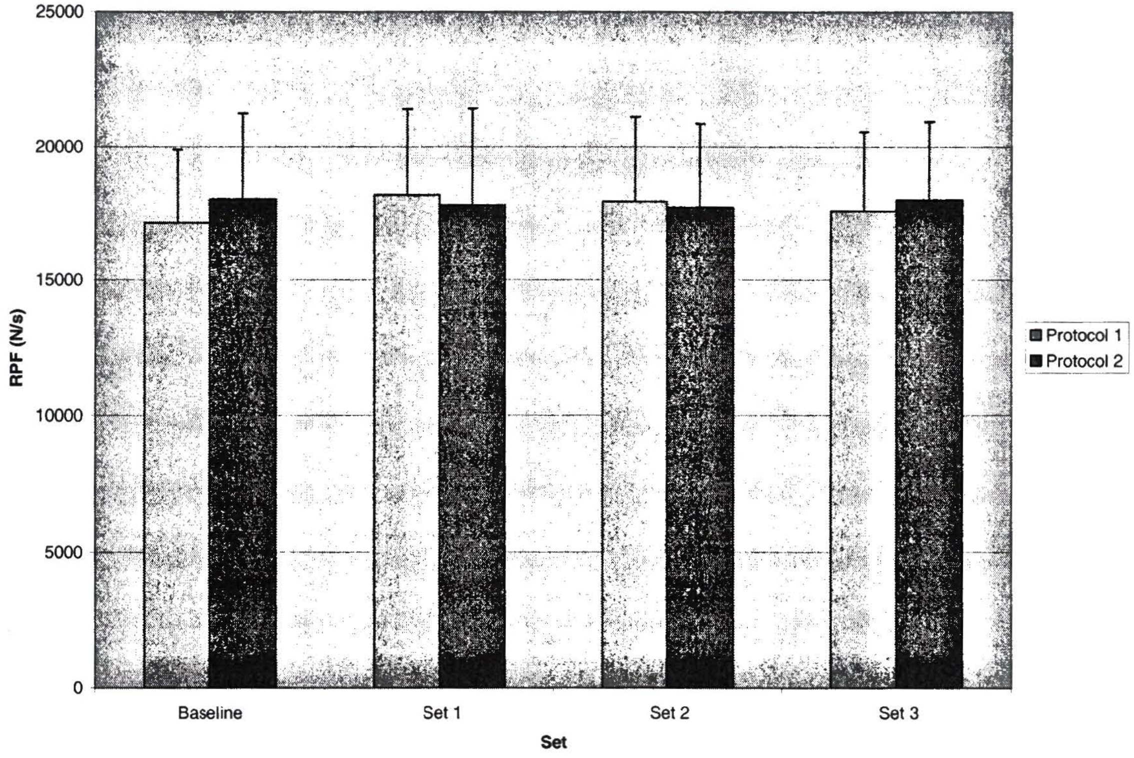

Figure 14. Maximal (SD) rate of peak force (N/s) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Maximal (SD) RPF (N/s) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

No significant effect was observed across trial 1 and 2 for maximal PV (F= 2.936; p> 0.01) (Fig. 15).

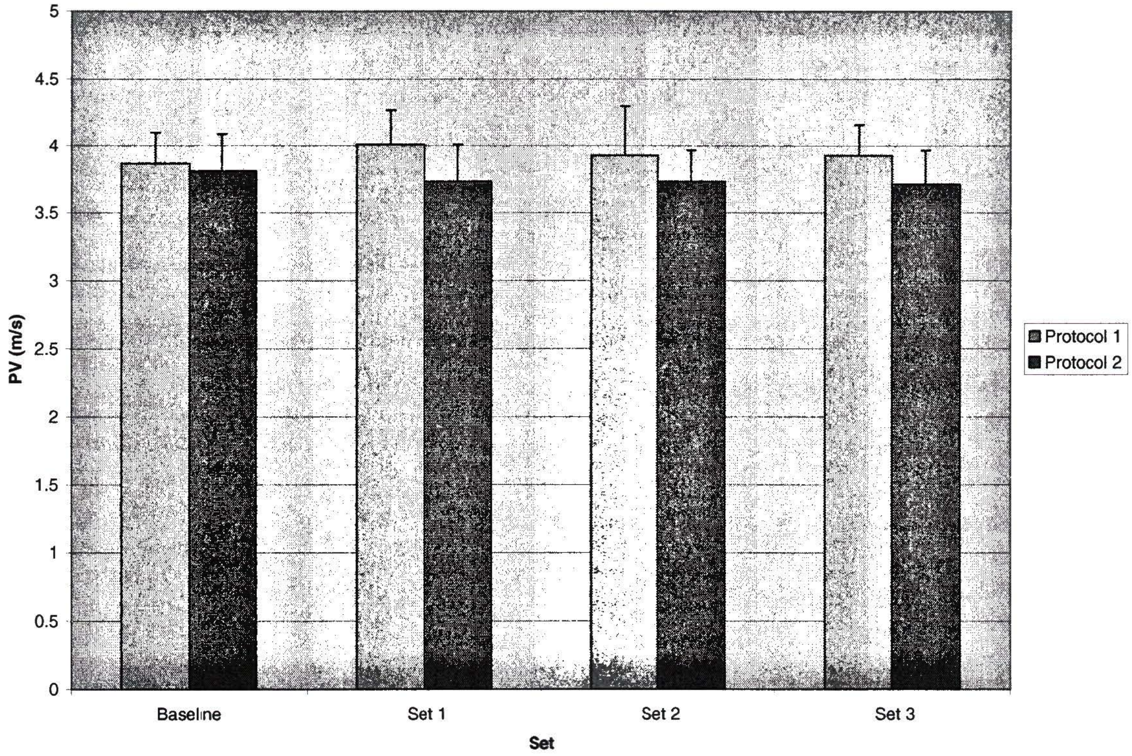

Figure 15. Maximal (SD) peak velocity (m/s) for four sets of CMJ (five jumps for each set). In protocol 1 each set of CMJ was separated by 4 min of rest, a 7-s MVIC, and another 4 min rest. Maximal (SD) PV (m/s) for four sets of CMJ (five jumps for each set). In protocol 2 each set of CMJ was separated by 8 min of rest (n=16).

Discussion

This study investigated the effect of a 7-s MVIC performed in the squat position at a knee-joint angle of 100 degrees on vertical jump performance (CMJ). In effect, three complex training sets were performed. Each complex training set was defined as a 7-s MVIC followed 4 min later by a set of 5 CMJ. Both group mean and maximal values for VJH, PP, PA, PF, RPF, and PV were linearly compared (each testing protocol was exclusive of each other) and were also compared across testing protocols 1 and 2. Correlations were also performed with respect to both absolute and relative strength and the change in the six dependent variables between the two protocols.

There were no significant differences in mean or maximal values for the six dependent variables across the four sets linearly or across testing protocols, with the exception of a significant decrease in maximal PP in testing protocol 2. It could be argued that due to the number of dependent variables compared the decrease in PP found in protocol 2 was a spurious finding. Thus, 7-s MVICs performed over three consecutive complex training pairs did not have a significant effect on mean or maximal values for VJH, PP, PA, PF, RPF, or PV.

These results are not in agreement with the fundamental rationale underlying complex training. Complex training involves the pairing of biomechanically similar resistive training exercises, performed set for set within a single training session. Proponents of complex training suggest that heavy loading of a given muscle group acts to "excite" that muscle group and the corresponding neuromuscular system and consequently enhance performance of subsequent activities (Chu, 1991; Young et al., 1998). That is, heavy resistance loading of the neuromuscular system elicits a state of potentiation that can be exploited to enhance performance. Both neurogenic and myogenic mechanisms have been proposed as the cause of any possible potentiation in performance (Stuart et al., 1988; Trimble and Harp, 1998).

Duthie et al. (2002) performed a similar study in which three different testing protocols were compared over three sets. The three protocols consisted of one in which three sets of a plyometric exercise (jump squats) were performed prior to the execution of three sets of a resistance exercise (half squats); a second protocol reversed this order and a third protocol in which the two exercises were alternated- i.e. the plyometric exercise followed the resistance exercise. Participants were 11 trained females aged between 19 and 31 years. A 3-RM was used as the stimulus and participants were required to descend to a knee-joint angle of 90 degrees. The jump-squats were performed in a modified Smith machine with the bar resting on the participants' shoulders from a fixed knee-joint angle of 90 degrees. A 5-min rest period followed all trials. No significant difference in jump squat performance between each of the protocols was found. However, there was a significant correlation between strength and the difference in PP and PF within the training methods.

Although the results from the Duthie et al. (2002) are similar to those of the present study, a number of differences with respect to the testing procedures exist. The present study used an isometric contraction while Duthie et al. (2002) used a dynamic contraction. The rest period was 5 min compared to 4 min in the present study. The present study used a non-loaded, non-fixed CMJ as the performance measurement instead of a loaded CMJ from a fixed knee-joint angle. And, although both subject pools were trained, Duthie et al. (2002) used a female population rather than a male population as in the present study. These findings support the postulate that, regardless of categorical or training variables, heavy loading of the neuromuscular system does not result in the enhancement of performance.

Hyrsomallis and Kidgell (2001) also found no significant difference in an exercise following a heavy resistance exercise. The researchers measured performance of explosive push-ups following a 5-RM bench press in twelve trained participants ($\overline{X}$ =22.8). A 3-min rest period between the resistance exercise and the ployometric exercise was used. No significant enhancement of the power activity was found following the resistance exercise.

The findings of Hrysomallis and Kidgell (2001) are also in agreement with the present study. The main difference between their study and the present study is the fact that they targeted the upper body rather that the lower body and a dynamic exercise rather than an isometric contraction was used as the stimulus. The rest period also varied, 3 min compare to 4 min in the present study. Therefore, again this would seem to lend support to the postulate that regardless of categorical or training variables, heavy loading of the neuromuscular system does not result in the enhancement of performance.

Scott and Docherty (in press) investigated the acute effects of heavy dynamic loading on both vertical (VJ) and horizontal (HJ) jump performance. They used a 5-RM squat exercise performed to a 90-degree knee-joint angle. A 5-min rest period was used between stimulus and performance measurement. The subject pool consisted of 19 trained males. The researchers failed to find any significant improvement in jump performance.

These findings are also in agreement with the present study, and again suggest that trained university-aged athletes do not experience enhanced performance of plyometric exercises following heavy resistance work. It should again be noted that, this study, unlike the present investigation, used a dynamic rather than isometric contraction.

Young et al. (1998) found a significant improvement in mean vertical loaded countermovement jump (LCMJ) performance after using a 19 kg load for the jump squat and a 5-RM squat exercise as the stimulus. A 4-min rest period was incorporated. Ten trained males took part in the study. The researchers postulated that a 5-RM set of back squats performed prior to the execution of a set of 5 LCMJ elicited a potentiated state in which the activity was enhanced. This enhancement in performance may have been due to either neurogenic or myogenic mechanisms or a combination of both.

The findings of Young et al. (1998) are not in agreement with the findings of the present study. Both studies used trained males of a similar age, but differed with respect to training variables. It could be argued that the use of a dynamic contraction (5-RM) is preferable to a MVIC. However, this raises questions regarding the inability to elicit performance enhancement in the Duthie et al. (2002) and Hyrsomallis and Kidgell (2001) studies. Perhaps the 4-min rest period used by Young et al., (1998) or the combination of the training variables incorporated in the study, allowed for the potentiation in performance. Another possible explanation could be due to the ordering effects of the testing protocol. Young et al. (2002) performed the control sets of jumps in the same session as the post-loading jumps were performed. That is, the participants performed a set of LCMJ followed by a rest and then another set of LCMJ (pre-loading). The lack of a significant increase in jump height indicated that there were no learning effects.

However, following a rest after the LCMJ (pre-loading) the 5-RM squat was performed and after another rest period the final set of LCMJ was performed. Because this sequence was performed in the same session, it could be argued that it was a combination of the first two sets of LCMJ and the 5-RM which resulted in the 2.8% improvement in jump height rather than the 5-RM back squat.

Gullich and Schmidtbleicher (1996) loaded participants using 3-5 unilateral leg-press maximal voluntary isometric contractions (MVICs). Following the loading of the neuromuscular system, subjects performed vertical countermovement jumps (CMJs) and depth jumps (DJs) on a Kistler dynamometric platform. The mean of eight jumps was calculated for the sets of jumps pre- and post-loading. They found that following three independent MVICs the participants jumped an average of 3.3% higher than in the set of jumps prior to the loading. These results represented a significant mean improvement in vertical jump height ($p<0.001$).

Although the results vary between the Gullich and Schmidtbleicher (1996) study and the present investigation, a number of similarities do exist. Both studies used isometric contractions, although quite different (unilateral compared to bilateral), as a stimulus and CMJ as a performance measurement. Both studies also used trained males as a subject pool. However, the participants who took part in the Gullich and Schmidtbleicher study were considerably better trained. While the rest period in the present study was consistent at 4 min, the rest period ranged from 3-5 min in the Gullich and Schmidtbleicher study. Some possible explanations for the differing results include the difference in isometric contraction used, the difference in rest period, or the difference in training status between the two subject pools. It could be argued that unilateral isometric contractions sum to a greater maximal strength than that attained using a bilateral isometric contraction (Vandervoort, Sale & Moroz, 1984).

Radcliffe and Radcliffe (1996) conducted a study in which five warm-up protocols were performed: a standard warm-up; a warm-up plus four sets of back squats at 75-85% 4-RM; a warm-up plus four sets of four power snatches at 75-85% 4-RM; a warm-up plus four sets of four loaded jumps with 15-20% body weight added; and a warm-up plus four sets of four unloaded jumps. These warm-ups were performed one per day on nonconsecutive days in random order. Following the warm-up protocols, three maximal effort horizontal countermovement jumps (HCMJ) were performed. The results indicated that, for males (the same results were not seen in females), the jump distance was significantly greater after the warm-up-plus-snatch protocol than after the standard warm-up alone. The researchers concluded that using the power snatch in a warm-up protocol significantly improved horizontal countermovement jump performance.

Radcliffe and Radcliffe (1996) used a dynamic rather than isometric contraction and used a shorter rest period, 3 min, than the present study. They also used a horizontal, rather than vertical jump as the performance measurement. The differing results may have been due to any of these factors. This raises a question regarding the transferability of vertical and horizontal planes with respect to loading and performance.

It has been found that a significant correlation exists between strength and the achievement of a potentiated state in which power activities may be enhanced (Duthie et al., 2002; Gullich & Schmidtbleicher, 1996; Young et al., 1998). Gullich and Schmidtbleicher (1996) suggested that elite power athletes are better equipped to capitalize on the phenomenon of PAP, but provided no statistical support for this postulate. Both Duthie et al., (2002) and Young et al., (1998) performed correlations and found significant correlations between absolute strength and jump performance ($p < 0.05$ and $p < 0.02$, respectively). Duthie et al. (2002) found significant correlations between absolute strength and changes in PP ($r = 0.66$) and PF ($r = 0.76$). Young et al. (1998) found a significant correlation between absolute strength and VJH ($r = 0.73$). Correlations (two-tailed, $p=0.01$) between both absolute and relative strength and the six dependent variables were performed using both mean and maximal values. The present study found a significant correlation between absolute strength and PA ($r = 0.692$) using mean values. Young et al., (1998) correlated absolute strength with VJH only, while Duthie et al. (2002) correlated absolute strength with PP, PF and jump performance. However, the significant correlation found by Young et al. (1998) was not replicated by Duthie et al., (2002). Of the 24 correlations performed in the present study, only one was significant when adjusted by the Bonferroni procedure. The practical significance of the correlations in all three of these studies is open to interpretation.

The correlation coefficient values determined in the Duthie et al. (2002) study suggest that absolute strength accounts for 43.56% of the variance in PP and 57.76% of the variance in PF. The value of $r = 0.73$ found in the Young et al. (1998) study suggests that absolute strength explains 53.29% of the variance in jump performance. Although perhaps a spurious finding ($r = 0.692$) it could be argued in the present study that absolute strength accounts for 47.89% of the variability in PA. It is important to note that these correlations represent a relationship rather than cause and effect. When discussing the relevance of these correlations, the strength of these correlations needs to be addressed. The variance explained in the four relationships above range from 43% to 58%. It could therefore be argued that perhaps other factor(s) are playing a role in predicting PP, PF, VJH and PA. A regression equation may be more appropriate in attempting to predict an outcome measure.

Various similarities and differences exist between the present study and the six studies discussed above. It is difficult to come to any conclusions with respect to how best to elicit a potentiated state and express it via a performance measurement due to the lack of consistency with respect to training variables in the existing studies. It is possible that because the studies using dynamic contractions failed to enhance performance, that dynamic contractions are inadvisable when attempting to elicit PAP. However, Young et al. (1998) succeeded in improving jump performance using a 5-RM. Most of the training variables used in a study which successfully enhanced performance, have also been incorporated into studies which have failed to elicit a potentiated state. A number of training variables, as well as categorical variables, must be considered when examining the potential effects of PAP on perfromance. The training variables include: Type of contraction, intensity, volume, rest interval(s) between possible multiple sets, rest interval before execution of the performance activity, and the possibility different muscle groups may respond differently. The categorical variables include: Training status, training age, chronological age, genetics, anthropometric measurements, gender, relative strength, and absolute strength.

The present study attempted to choose parameters for each of the above variables which would allow for the greatest possibility of enhancing vertical jump performance. Enhancement of vertical jump performance was not observed in this study and may have been due to a number of different reasons. Perhaps the elicitation of a potentiated state as observed by Gullich and Schmidtbliecher (1996), Radcliffe and Radcliffe (1998) and Young et al. (1998), was a result of something other than excitation of the neuromuscular system. Studies in this field are currently limited. Further research is required to substantiate the effects of PAP in a training setting as well as identify the loading and resting parameters that may optimize training and performance.

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Appendix A: A review of PAP

Introduction

The contractile response of skeletal muscle is partially determined by its contractile history (MacIntosh & Rassier, 2002). Contractile stimulation results in attenuation of performance due to fatigue. However, at the same time fatigue is realized, postactivation potentiation (PAP) is also elicited. PAP refers to the phenomenon by which acute muscle force is enhanced as a result of contractile history. Loading of the neuromuscular system elicits an "excited" or "sensitive" state in which performance is enhanced. Contractile activity produces both fatigue and PAP and it is the balance between the two that determines whether the subsequent response is enhanced, diminished or does not change. PAP has been examined in a number of studies, as has its mechanisms. Although there is consensus regarding the existence of PAP, the mechanisms underlying it are yet to be determined. Post-tetanic potentiation (PTP) is a potentiated state following an evoked tetanic contraction, whereas PAP is a potentiated state following any stimulus (Sale, 2002). For the purpose of this paper the term PTP will not be used. Rather, the more encompassing term PAP will refer to any post-stimulus potentiated state.

It has been suggested that the elicitation of PAP could improve athletic performance (Güillich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996; Young, Jenner & Griffiths, 1998). Generally, two premises have been put forward as to how PAP may be manipulated to enhance performance. Firstly, it has been postulated that the elicitation of PAP prior to execution of an activity could enhance the performance of that activity in an acute manner (Güillich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996; Young et al. 1998). According to this premise the possibility exists that elicitation of PAP through intense loading of the neuromuscular system in a warm-up protocol prior to execution of an activity may enhance that activity. However, for the most part, studies to date have not examined the acute enhancement of performance via PAP as reflected in a performance measure. Studies examining PAP have usually examined electrically evoked twitch characteristics. As such, these studies have tended to achieve a high degree of internal validity at the cost of reduced external validity.

It has also been postulated that the manipulation of PAP throughout a training macrocycle may allow the athlete to train at a higher level and thereby realize greater chronic adaptation (Adams, O'Shea, O'Shea, & Climstein, 1992; Lyttle, Wilson & Ostrowski, 1996; Verkhoshansky & Tatyan, 1973; Young et al., 1998). Studies have compared a complex training method to other training methods aimed at developing strength and power and concluded that the complex method is superior (Adams et al., 1992; Lyttle et al., 1996; Verkhoshansky & Tatyan, 1973). Complex training involves the coupling of a resistance training exercise with a biomechanically similar plyometric exercise. These "complex pairs" attempt to capitalize on the phenomenon of PAP and are typically performed over repeated trials. Research on acute PAP is limited, and nonexistent with respect to chronic PAP, in practical settings. Further research is necessary before any conclusions can be made as to the practical applicability of PAP with respect to enhancing performance or achieving high levels of chronic adaptation (Ebben & Blackard, 1997; Ebben & Watts, 1998; McBride, Triplett-McBride, Davie & Newton, 2002; Potteiger, Lockwood, Haub, Dolezal, Almuzaini, Schroeder, et al, 1999; Wagner & Kocak, 1997).

Evidence

PAP is traditionally assumed to have been elicited if improved post-stimulus performance is achieved. However, because the contractile response of muscle is affected by its contractile history, which would include both PAP and fatigue, the measurement of PAP is confounded. PAP acts to improve performance, while fatigue acts to attenuate performance. Although PAP may have been elicited as a result of a given stimulus, it may not appear in the form of an enhanced post-stimulus response, due to the counteracting effect of fatigue. The coexistence of fatigue and PAP may result in a net potentiated state, a net attenuated state or a constant state as compared to the pre-stimulus state (MacIntosh & Rassier, 2002). Therefore, when discussing the elicitation or nonelicitation of PAP in the following studies it should be noted that with respect to this paper the operational definition of PAP is a net potentiated response. In other words, with respect to studies in which post-stimulus measurements were not enhanced, rather than concluding that PAP was not elicited, it will be assumed a net potentiated effect was not realized.

Contractile properties

A number of studies have been conducted over the last 25 years in which the twitch contractile properties of muscle have been examined pre- and post-stimulus. Research has shown that post-stimulus twitch contractile properties are enhanced when compared to pre-stimulus twitch contractile properties (Alway, Hughson, Green, Patla & Frank, 1987; Hamada, Sale & MacDougall, 2000; Hamada, Sale, MacDougall & Tarnopolsky, 2000; Paasuke, Ereline & Gapeyeva, 2000; Petrella, Cunningham, Vandervoort & Paterson, 1989). These studies were very consistent in their description of increased twitch tension, increased rate of tension development and decreased relaxation time.

Paasuke et al. (1998) compared twitch contractile properties between endurance and power athletes in resting and PAP conditions. Maximal force values, rate of force development and rate of relaxation were significantly higher for the potentiated twitches compared to the resting twitches for both endurance and power athletes. A similar study by Paasuke et al. (1999) compared the contractile properties of young and middle-age men in resting and PAP states. It was concluded that potentiated twitch maximal force was only significantly higher for young men. Paasuke et al. (2000) also compared potentiated contractile characteristics in pre-pubertal boys and post-pubertal young men. The peak twitch force was significantly greater in the potentiated state compared with the rested state for all three groups. The methodology was similar in all three studies. Hamada, Sale and MacDougall (2000) examined PAP in endurance athletes. They concluded that PAP was enhanced in the trained muscles of endurance athletes. It was postulated that a reduction in required motor unit firing rates may counteract low-frequency fatigue and enhance endurance performance. Hamada, Sale, MacDougall & Tarnopolsky (2000) examined the relationship between fibre-type distribution and PAP. It was found that muscles with a larger percentage of Type II fibres and shorter contraction times expressed greater PAP. Vandervoort et al. (1983) also performed an experiment in which twitch force was potentiated as a result of high-intensity stimulus. Unlike the studies in which the execution of an athletic activity was used to determine the extent of PAP (Güillich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996; Young et al., 1998), the six studies discussed above measured PAP as the difference in electrically evoked twitch characteristics pre- and post-stimulus.

A number of studies have been conducted in order to clarify the mechanisms by which PAP occurs. Although these studies did not set out to provide evidence as to the existence or nonexistence of PAP, some of them have indirectly done so. Evidence for the existence of PAP has been provided by studies investigating the role of myosin light chain (MLC) phosphorylation in PAP (Grange & Houston, 1991; Manning & Stull, 1979; Manning & Stull, 1982; Stuart, Lingley, Grange & Houston, 1987; Tubman, MacIntosh & Maki, 1996). These studies measured PAP elicited by electrically evoked twitches.

Performance measurements

The results of research that has attempted to elicit and subsequently measure PAP via a performance activity have been equivocal. Unlike the general consensus regarding the potentiation of twitch contractile properties, improvement of a performance measurement has been less consistent. Both Güillich and Schmidtbleicher (1996) and Young et al. (1998) found increases in the performance of power activities following high-intensity loading. Güillich and Schmidtbleicher (1996) loaded participants using 3-5 unilateral leg-press maximal voluntary isometric contractions (MVICs). Following this loading of the neuromuscular system, subjects performed vertical countermovement jumps (CMJs) and depth jumps (DJs) on a Kistler dynamometric platform. The mean of eight jumps was calculated for the sets of jumps pre- and post-loading. They found that following three independent MVICs the participants jumped an average of 3.3% higher than in the set of jumps prior to the loading. These results represented a significant mean improvement in vertical jump height ($p<0.001$). Young et al. (1998) found a significant improvement

(2.8%) in vertical jump height in a set of jumps post- versus pre-loading. The investigators preceded a five-repetition-maximum (5-RM) half-squat with a set of five loaded countermovement jumps (LCMJs). Another set of five LCMJs was performed four minutes post-loading. Vertical jump height attained in the set of jumps following the 5-RM half-squat was statistically greater than that attained in the set of jumps preceding the 5-RM squat ($p<0.05$). Young et al. (1998) attempted to control for any combined effect from both the 5-RM squat and the LCMJ-pre on the final LCMJ-post by incorporating a set of LCMJs before the LCMJ-pre into the experimental design. They found no significant difference in vertical jump height between the first two sets of LCMJs. However, potential ordering effects cannot be completely ruled out in this study.

Two additional studies have also presented interesting results. Unfortunately, only limited information is available for both studies. Radcliffe and Radcliffe (1996) conducted a study in which five warm-up protocols were performed: a standard warm-up; a warm-up plus four sets of back squats at 75-85% 4-RM; a warm-up plus four sets of four power snatches at 75-85% 4-RM; a warm-up plus four sets of four loaded jumps with 15-20% body weight added; and a warm-up plus four sets of four unloaded jumps. These warm-ups were performed one per day on nonconsecutive days in random order. Following the warm-up protocols, three maximal effort horizontal countermovement jumps were performed. The results indicated that, for males, the jump distance was significantly greater after the warm-up-plus-snatch protocol than after the standard warm-up alone. The researchers concluded that using the power snatch in a warm-up protocol significantly improved horizontal countermovement jump performance. Gilbert, Lees and Graham-Smith (2001) conducted a study in which the stimulus consisted of five single 1-RM squats performed with a 5-minute rest interval between repetitions. It was concluded that although this stimulus produced no significant changes in isometric MVC, it was sufficient to elicit PAP as reflected in the isometric rate of force development.

However, a number of studies have failed to demonstrate a net potentiated effect. Paasuke et al. (2000) used a fatiguing protocol and found subsequent twitch maximal force was significantly less compared to a rested condition. It was postulated that the post-fatigue force depression was a reflection of low-frequency fatigue. They concluded that muscle fatigue outweighed any potential benefits of PAP, resulting in a decrease in force-generating capacity, a decrease in the rate of tension development, and an increase in relaxation time.

Hrysomalis and Kidgell (2001) attempted to elicit PAP in the upper body. Performance, as measured by explosive push-ups, was not enhanced as a result of a 5-RM bench press. This study fundamentally differed from those of Güillich and Schmidtbleicher (1996) and Young et al. (1998) in three ways. Firstly, Hrysomallis measured upper-body acute power enhancement rather than lower-body acute power enhancement. Secondly, they utilized a shorter rest interval of 3 minutes. Lastly, the "non-stimulated" power movement was performed on a different day, rather than pre-stimulus. Thus, any possible potentiation as a result of the pre-stimulus execution of the movement combined with the resistive exercise was nonexistent. The authors suggested that the non-elicitation of PAP could be due to a number of reasons, including the supposition that the requirements to elicit PAP in the upper body may differ from those required to elicit PAP in the lower body.

Two studies performed at the University of Victoria also failed to elicit any enhancements in performance following a resistive exercise. Scott and Docherty (in press) found no improvements in either vertical or horizontal jumps following a 5-RM squat. Some subjects did in fact enhance performance post-stimulus, whereas others attenuated performance. However, across the subject pool significant improvements in performance were not observed. This supports the postulation that PAP is an individual-specific phenomenon. A. King (unpulished thesis) found no enhancement in vertical jump data following 2.5-, 5-, and 10-second MVICs performed in the squat position. It was postulated that the 10-second and 5-second contractions may have elicited fatigue sufficient to outweigh any PAP. With respect to all contraction durations, individual-specific variables such as training status and fibre-type composition may have been responsible for the lack of enhancement in the performance measurement.

Gossen and Sale (2000) conducted a study in which a 10-second MVIC was followed 15 seconds later by dynamic contractions. Performance, as measured by dynamic knee extension, was not enhanced post-stimulus, but rather was attenuated. The researchers concluded that the 15-second rest interval between resistive exercise and performance measurement was insufficient. That is, at 15 seconds post-stimulus the effects of fatigue elicited via the 10-second MVIC were greater than the benefits of any elicited PAP.

A study conducted by Duthie, Young and Aitken (2002) also failed to find an enhancement in performance. This study was unique in that it attempted to examine power performance in loaded jump squats over three consecutive trials using three different protocols. The three protocols involved the combination of three sets of 3-RM half-squats with three sets of four jump squats performed at 30% of 1-RM. One protocol attempted to take advantage of PAP over the three sets via a complex (referred to as contrast in the study) training method. However, performance enhancement was not observed in any of the three sets of four jump squats in the complex protocol, or any of the other training protocols. Although enhancement of performance was not detected, a correlation between absolute strength and performance was determined with respect to the complex protocol. Specifically, absolute strength was correlated to peak power and maximal force at (r=0.66) and (r=0.76), respectively. Thus, 43.56% of the variability in peak power and 57.76% of the variability in maximal force are directly predictable from the variability in absolute power. This leaves approximately half of the variability in both peak power and maximal force unexplained. It is important to note that this correlation represents a relationship rather than cause and effect. Stronger subjects, although not achieving enhancement in performance, did realize a smaller decrement in the data measurements following the resistive exercise (as compared to the pre-resistive exercise values) than did the less strong subjects. This suggestion is supported by similar findings byYoung et al. (1998). The correlation could be interpreted to partially explain why subjects with greater absolute strength were better able to benefit from a training modality when resistive exercises are followed by power exercises in an alternating fashion.

Evidence for the existence of PAP with respect to twitch contractile properties is abundant. Evidence also exists for PAP in more practical performance-type measurements. However, the evidence for PAP in performance measurements has been somewhat confounded by studies which have not found enhancements in post-stimulus performance.

Mechanisms

The mechanisms of PAP are as yet not well understood. The principal mechanisms have been suggested to be both neurogenic and myogenic. It has been postulated that loading of the neuromuscular system results in the nervous system becoming "sensitive" or "excited" and that, in this state, performance is enhanced (Güillich & Schmidtbleicher, 1996; Lev-Tov, Pinter & Burke, 1983; Trimble & Harp, 1998). Recent literature has concentrated on phosphorylation of the myosin light chain (MLC) as the primary mechanism of PAP. Studies have shown a positive correlation between phosphorylation of the MLC and potentiation of post-stimulus twitch contractile properties. Both mechanisms will be discussed in more detail.

Neurogenic mechanisms

Although it has been popular for researchers to postulate that potentiation may be due to neural factors (Güillich & Schmidtbleicher, 1996; Young et al., 1998), evidence to support this hypothesis is limited. Hultborn, Illert, Nielson, Paul, Ballegaard and Weise (1996) and Lev-Tov et al. (1983) have suggested that either PAP or postactivation depression could be a result of changes in neurotransmitter release from Ia nerve fibres. Hultborn et al. (1996) have suggested a decrease in presynaptic inhibition of the Ia afferents with voluntary contraction. This may allow for a positive feedback loop to the motor neuron. They postulate that this is under the control of cortical structures. Trimble and Harp (1998) used a concentric-eccentric contraction to elicit a post-stimulus potentiated state of the H-reflex. They postulated the potentiated H-reflex was due to an increased post-synaptic discharge of neurotransmitter from Ia nerve terminals. They concluded this discharge resulted from the high-frequency impulses and the consequent efficacious afferent volley. The researchers reasoned that the efficacious afferent volley coupled with a positive feedback loop may allow for PAP to be elicited via a concentric-eccentric contraction. Gullich and Scmidtbliecher (1996) also measured the H-reflex post-stimulus and postulated that an increase in amplitude indicated that more motor units had been activated compared to pre-stimulus levels. According to Henneman's size principle, the additional motor units would be the next largest (i.e., type II, fast-twitch units). However, it could be argued that the increase in amplitude is not necessarily an indicator of increased motor unit activation (Zehr, 2002).

Myogenic mechanisms

More recently, the emphasis has shifted from neurogenic to myogenic mechanisms that are responsible for PAP. A number of studies have examined the relationship between phosphorylation of the MLC and PAP (Grange & Houston, 1991; Klug, Botterman & Stull, 1982; Manning & Stull, 1979; Manning & Stull, 1982; Moore & Stull, 1984; Stuart et al.,1987; Tubman et al., 1996). These studies examined twitch contractile characteristics and found a correlation between the extent of MLC phosphorylation and potentiation. As such, it has been suggested that MLC phosphorylation may play a modulatory role in PAP. Phosphorylation of the MLC is catalyzed by myosin light chain kinase (MLCK) (Sweeney, Bonita & Stull, 1993; Szczesna, Zhao, Jones, Zhi, Stull & Potter, 2002). MLCK is activated with an increase in Ca^{2+} concentration (due to contraction of skeletal muscle) and the binding of the Ca^{2+}-calmodulin unit to MLCK (Houston, Green & Stull, 1985; Klug et al.,1982). Once MLCK is activated, there is an increase in MLC phosphorylation. Rassier and MacIntosh (2002) postulated that this increase in MLC phosphorylation subsequently leads to an increase in the sensitivity of the actin/myosin contraction complex to Ca^{2+} and an enhancement in submaximal contractile properties as a result of an increased net rate of actin/myosin crossbridging. That is, while there is an increase in the rate of actin/myosin crossbridge attachments, this is not accompanied by increased rates of detachment of the actin/myosin crossbridges.

Tubman et al. (1996) examined the contractile properties of muscle and concluded that MLC phosphorylation was not the sole factor contributing to PAP. They suggested that other mechanisms were also responsible. Perhaps emphasis has shifted from neurogenic to myogenic mechanisms due to the practicality of conducting research on myogenic rather than neurogenic mechanisms and the relatively higher internal validity that is possible in studying myogenic mechanisms. Whereas phosphorylation of the MLC is perhaps better understood than the proposed neurogenic mechanisms of PAP, it should once again be stressed that the mechanisms of PAP per se are not well understood.

Fatigue and PAP

Both PAP and fatigue result from the contractile history of muscle. It has been suggested that PAP and fatigue coexist (MacIntosh & Rassier, 2002; Rassier & MacIntosh, 2002). PAP can be readily and clearly observed in the event of post-stimulus enhancement of either contractile characteristics or performance measurement. However, in the absence of enhancement, potentiation is more difficult to quantify. Potentiation due to a stimulus may act to lessen the decrement in performance due to fatigue as a result of that same stimulus. PAP could also interact with fatigue to allow for constant pre- and post-stimulus measurements. Duthie et al. (2002) postulated that the smaller decreases observed in performance of a dynamic activity by strength athletes as opposed to untrained subjects, following a 3-RM, was evidence that PAP was better elicited in "stronger" individuals. However, in this case, performance was not enhanced but attenuated to a lesser degree.

Evidence as to the coexistence of PAP and fatigue has been presented by a number of researchers. Tubman et al. (1996) demonstrated that fatigued muscle could be potentiated and concluded that PAP in fatigued muscle was similar to that seen in rested muscle. Rankin, Enoka, Volz and Stuart (1988) demonstrated an enhanced twitch response in muscle following a fatiguing protocol. At the same time, the tetanic contractile response was depressed, indicating the coexistence of both PAP and fatigue. Because both fatigue and PAP are effects of contractile history and act to offset each other, it is difficult to measure PAP.

Fibre type

PAP is elicited to a greater degree in fast-twitch (FT) Type II muscle fibres (Hamada, Sale, MacDougall & Tarnopolsky, 2000). Therefore, muscles with a greater percentage of FT fibres tend to exhibit greater PAP (i.e., the faster gastrocnemius compared to the slower soleus). Also, individuals who exhibit greater percentages of FT fibres within a given muscle tend to realize greater PAP (Sale, 2002; Sweeney, Bowman & Stull, 1993). Confounding this generalization is the fact that FT fibres are also the least resistant to fatigue, which will influence net PAP measurements. Sale (2002) elucidated the force-frequency relationship with respect to PAP, arguing that because explosive activities require high motor unit firing rates (as seen in FT fibres), the possible effect of PAP on peak force measurements is negligible; on the other hand, slow-twitch (ST) fibres that are involved in activities requiring only low motor unit firing rates have the greatest to gain from PAP. That is, rather than affecting high-frequency force, PAP has more influence on low-frequency force (Sale, 2002). Further complicating the issue is the effect of PAP on the rate of force development which may evidence itself at high frequencies and is largely responsible for enhancement with respect to FT fibres.

Studies examining twitch characteristics with respect to fibre type in a potentiated state have determined that FT Type II fibres demonstrate greater PAP (Hamada, Sale, MacDougall & Tarnopolsky, 2000; Paasuke et al.,1998; Vanervoort et al., 1983). Hamada, Sale, MacDougall & Tarnopolsky (2000) induced PAP in the knee extensors and subsequently performed needle biopsies of the vastus lateralis to determine that subjects exhibiting the highest PAP had a greater percentage of Type II fibres. The researchers also reasoned that the shorter pre-stimulus twitch time to peak torque displayed by the subjects exhibiting the greatest PAP could be inferred to support the conclusion that the subjects displaying the highest PAP had the highest percentage of Type II fibres. This inference was supported by the biopsy data.

The studies by Duthie et al. (2002), Güillich & Schmidtbleicher (1996) and Young et al. (1998), in which attempts to elicit PAP and subsequently measure it via a performance measurement, were consistent in their conclusions that better-trained individuals exhibited greater PAP. Güillich & Schmidtbleicher (1996) reasoned that the relatively higher degree of FT fibres in the gastrocnemius muscle as compared to the soleus was at least partially responsible for the greater PAP elicited in the gastrocnemius. Both Young et al. (1998) and Duthie et al. (2002) suggested that high-level strength athletes, with presumably higher proportions of Type II fibres, were better able to elicit PAP. Correlations between absolute strength and both peak power (r=0.66) and maximal force (r=0.76) supported this conclusion. However, no measurement (e.g., muscle biopsies) was made to verify that the stronger subjects had higher percentages of FT fibres.

PAP has also been exhibited in endurance athletes, who presumably have muscle made up of higher percentages of ST fibres (Hamada, Sale & MacDougall, 2000; Paasuke et al.,1998). Hamada, Sale & MacDougall (2000) concluded that PAP was elicited in endurance athletes but was specific to the muscles that were trained. The authors suggested that this may have been due to training adaptations, a greater resistance to fatigue, or both. The greater fatigue resistance of Type I fibres would increase the net PAP. Paasuke et al. (1998) recorded significant increases in twitch contractile properties of muscle in a potentiated compared to rested state for both endurance and power athletes. However, the increase observed in the power athletes was significantly higher than that in the endurance athletes. Because PAP is evident at low frequencies, it may counteract low-frequency fatigue and thereby increase net PAP by decreasing fatigue. Therefore, whereas PAP is realized in power or strength athletes (with a relatively high percentages of Type II fibres) primarily because of greater potentiation, PAP in endurance athletes (with a relatively low percentage of Type II fibres) may be due to a proportionately higher resistance to fatigue. Whether greater potentiation or less fatigue is affected, both processes would result in a greater net PAP.

Problems with eliciting PAP

In order to elicit a net potentiated state which can be assessed via a performance measurement (e.g., a countermovement jump) a number of factors must be considered. Ideally, the greatest level of PAP would be generated in combination with the least amount of fatigue. Following a stimulus aimed at achieving the greatest possible net PAP effect, a strategy devised to take advantage of the window in time when net PAP is greatest is necessary. The decay rate of PAP and the recovery rate from fatigue need to be considered in order to increase the probability of eliciting a net potentiated state in which performance may be enhanced. Some of the variables that must be considered when constructing a stratagem designed to elicit PAP, and subsequently measure it, will be discussed below.

Type of Stimulus

The two most common types of stimuli used when attempting to elicit PAP and measure performance enhancement are isometric contractions and dynamic concentric-eccentric (isonertial) contractions. Radcliffe and Radcliffe (1996) found significant increases in performance using an explosive dynamic contraction as the stimulus. Young et al. (1998) used a 5-RM squat to elicit enhancement in performance, whereas Hrysomallis & Kidgell (2001) and Scott & Docherty (personal communication) failed to elicit performance enhancement using a 5-RM. Both Gossen & Sale (2000) and King and Wenger (personal communication) failed to enhance performance using a maximal voluntary isometric contraction (MVIC). Güillich & Schmidtbleicher (1996) utilized isometric contractions as a stimulus to measure increases in performance. Isometric contractions have been used extensively to evoke PAP as measured in twitch contractile properties (Alway et al.,1987; Burke et al., 1976; Hamada, Sale & MacDougall, 2000; Hamada, Sale, MacDougall & Tarnopolsky, 2000; Paasuke et al., 1998; Paasuke et al., 1999; Paasuke et al., 2000; Petrella et al., 1989; Vandervoort et al., 1983), but success using isometric contractions with a dynamic performance measurement is limited.

Perhaps a dynamic stimulus is better transferred to a performance measurement which is dynamic.

Intensity of the stimulus

Both isometric and isonertial, maximal or near maximal, voluntary contractions have been commonly used by researchers in attempting to elicit PAP in a performance measurement. Güillich & Schmidtbleicher (1996) stated that short-term potentiation of explosive force is possible only if the contraction stimulus is at least 100% of 1-RM. They further stated that contractions of less than 85% of maximal do not induce potentiation of the nervous system. Support for the postulate that high-intensity loading of the neuromuscular system is necessary to activate both the proposed neurogenic and myogenic mechanisms of PAP exists (Duthie et al., 2002; Young et al., 1998).

Load

A variety of loads have been utilized in attempting to elicit PAP in a performance measurement. With respect to MVICs, 10 seconds is commonly used and has been suggested to be the optimal duration in eliciting PAP (Vandervoort et al., 1983). However, 5-second MVICs have also been used successfully in twitch contractile studies (Paasuke et al., 1998, 1999, 2000, 2000). Clarification of the 10-second MVIC would seem appropriate and relevant, specifically the duration for which maximal force output is maintained. Studies incorporating dynamic contractions have utilized low-repetition maximums (i.e., 3-RM or 5-RM). Although it has been suggested that MVICs may result in greater neuromuscular activation, this difference is likely negligible (Hrysomallis & Kidgell, 2001). Studies have been consistent in combining relatively high intensity with relatively low volume.

Rest interval

The type, intensity and volume of stimulus all relate to inducing PAP and coincidentally fatigue. The duration of the rest interval between the resistive exercise and the performance measurement is concerned with the rate of decay of PAP and the rate of dissipation of fatigue. The rest interval needs to be manipulated in such a way as to take advantage of that time when the difference between PAP and fatigue favors PAP the most. Gossen and Sale (2000) attempted to take advantage of elicited PAP immediately(approximately 15 seconds) after execution of the resistive exercise (approximately 15 seconds) and instead realized a postactivation depressed state. They concluded that fatigue outweighed any PAP after completion of the resistive exercise. The other two studies that failed to show enhanced performance (Duthie et al., 2002 and Hrysomallis & Kidgell, 2001) used 5-minute and 3-minute rest intervals respectively. The three studies which showed enhanced performance (Güillich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996; Young et al., 1998) used 3-minute-to-5-minute-20-second, 4-m and 3-minute rest intervals, respectively. Therefore, although there is some consensus regarding the duration of rest interval (3-5 minutes), this is no guarantee of eliciting PAP-enhancing performance.

Testing protocol

Studies attempting to measure PAP through performance have generally used variables of performance pre- and post-stimulus. The pre-stimulus measurement is a measurement of the performance activity prior to the stimulus. Thus, this measurement can take place prior to the stimulus, during the same testing session, or on another testing day. It has been postulated that there may be a combined effect of the pre-stimulus activity and the resistance exercise (Sale, 2002; Hrysomallis & Kidgell, 2001). That is, the pre-stimulus contraction itself may cause some degree of PAP. However, by the same logic, it would also hold that the pre-stimulus contraction could result in fatigue and work to attenuate the post-stimulus activity. Regardless of the net result of the timing of the pre-stimulus movement, it is necessary to consider the testing protocol when devising a strategy to enhance performance through PAP.

Training status

The training status of an individual has been postulated to affect the outcome of protocols designed to elicit PAP (Duthie et al., 2002; Güillich & Scmidtbleicher, 1996; Young et al., 1998). Both Duthie et al. (2002) and Young et al. (1998) found correlations between the absolute strength of subjects and the outcome data measurements -- that is, the greater the strength, the greater the performance enhancement or, in the case of Duthie et al. (2002), the less the decrement. Elite athletes may be better able to take advantage of PAP as a result of their training and consequent strength profiles. Therefore the training status of the subjects also needs to be considered.

Individual specificity

Further confounding the measurement of PAP through a performance activity is the postulate that there is high interindividual variability with respect to the time lines of both PAP and fatigue (Güillich & Schmidtbleicher, 1996). In order to determine the optimal values or most effective protocols for the factors discussed above, individual trial-and-error testing may be necessary. The inability to generalize training parameters used to elicit PAP raises questions as to the feasibility and efficacy of complex training or warm-up training protocols.

Practical Applications

The body of literature surrounding PAP describes two possible applications of PAP with respect to enhancing performance: Acute and chronic. Evidence in support of the use of intense loading of the neuromuscular system prior to performance of a one-time activity has been provided. Studies have been conducted in which one set of an exercise has been used as a stimulus and resulted in enhancements in performance, post-compared to pre-stimulus. The acute enhancement of power performance observed in these studies (Güillich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996; Young et al., 1998) suggests that high-intensity exercise incorporated into a warm-up routine improves acute performance in certain activities. However, a number of training variables must be considered when attempting to manipulate contractile history. These include:

1. Type of contraction (i.e., isometric, concentric-eccentric, etc.)
2. Intensity.
3. Volume (i.e. repetitions, sets, cadence, time under tension).
4. Rest interval(s) between possible multiple sets.
5. Rest interval before execution of the performance activity.
6. Different responses of different muscle groups.

It has also been suggested that PAP is individual-specific (Duthie et al., 2002; Gullich & Schmidtbliecher, 1996; Young et al., 1998). The proposed high interindividual variability associated with PAP prompts the consideration of categorical variables. These include:

1. Training status.
2. Training age.
3. Chronological age.

4. Genetics (i.e., fibre type composition).
5. Anthropometric.
6. Gender.
7. Relative strength.
8. Absolute strength.

Therefore, not only contraction type, intensity, volume and muscle group, but also the decay rate of PAP and the dissipation rate of fatigue need be considered for each individual athletic profile. The window of opportunity in which performance is possibly enhanced may be so small as to make incorporation of such exercises into pre-competition warm-ups inadvisable.

In order to determine optimal values for the six training variables, an athlete(s) would first need to be grouped according to the eight categorical variables. Once the athlete has been categorized, the type of contraction, intensity, volume and rest interval(s) can be set at optimal values through a series of trial- and- error experiments. Following this, a series of experiments would be performed to determine if PAP could be exploited to enhance performance. Thus, it is possible that in this manner parameters could be set for each homogenous group of individuals, thereby allowing the enhancement of acute athletic performance- that is, assuming PAP may be expressed in the enhancement of a performance measure.

Assuming contractile history may be manipulated to result in enhanced performance, the question of feasibility is raised. It would be a considerable task to determine training variable parameters for countless different athletic profiles. Assuming training variables were determined in conjunction with the categorical variables, a myriad of other implications could arise. For example, if it were determined that a 5-second MVIC performed in the squat position was optimal as a stimulus for a certain athletic profile in order to enhance high-jump performance, possible problems could include:

1. The availability of MVIC equipment at the site of competition.
2. Coordinating the PAP time line with the competition time line.
3. Subsequent jumps and any cumulative effects.

Issues of transferability could also arise. Whereas the aforementioned MVIC may enhance high-jump performance, it may not enhance performance of an activity such as a 100-metre sprint. The idea that this same MVIC may enhance performance throughout a prolonged activity such as a basketball or rugby game is unlikely.

It has also been suggested that the manipulation of PAP through a complex training protocol over a macrocycle may result in greater chronic adaptation (Duthie et al., 2002; Gullich & Schmidtbliecher, 1996).The concept of manipulating PAP in a training modality, such as complex training, requires scientific research. Studies have compared complex training to other modalities, but have not specifically examined PAP. Duthie et al. (2002) performed three sets of complex training in a study designed to investigate PAP. However, this was an acute study and therefore cannot elucidate on chronic adaptation resulting from PAP. If, as discussed in the preceding paragraph, training variable parameters could be determined for a given athletic profile, these parameters could perhaps be applied to multiple sets and performed over a training macrocycle. This training modality (complex training) could be compared to other modalities aimed at developing power and some conclusions as to the efficacy of PAP with respect to chronic adaptation could perhaps be drawn. However, it is possible that the parameters determined in order to enhance acute performance (assuming existence) could not be applied to multiple sets. It is also possible that a net potentiated state may not be elicited over consecutive sets (as was the case in the Duthie et al. study). It would again be necessary to perform a series of trial- and- error experiments to determine if, and how, a complex training modality is superior to other training programs in terms of developing power.

Assuming PAP could be exploited in such a way as to allow a complex training type of modality to result in superior gains in power, as compared with similar training modalities, other obstacles could arise. For example, if it were concluded that in order to optimally develop lower-body power in a certain athletic profile four sets of a given complex pair should be performed and that the optimal rest intervals between the resistive exercise and the plyometric exercise were 4, 6, 10 and 20 minutes respectively, problems with efficiency arise. Athletes and coaches may not be willing to spend 45 minutes performing four complex sets. This is an extreme example and probably not likely. However, the feasibility of determining training variable parameters with the intention of manipulating PAP for acute or chronic athletic performance enhancement is even less.

Conclusions

Postactivation potentiation is a phenomenon that exists. However, its elicitation and reflection in the enhancement of an athletic activity has been equivocal. Assuming PAP can be exploited to enhance acute performance, the determination of parameters for training variables specific to varying athletic profiles, muscle groups and athletic activities makes the widespread use of PAP impractical. Certain elite athletes possessing both the time and resources necessary to establish a set of training parameters specific to themselves and their athletic activity could possibly benefit from PAP. With respect to exploiting PAP and chronic adaptation, no scientific research exists. The lack of scientific research may reflect the impracticality of conducting such research. Whatever the reason, evidence to support any conclusion regarding PAP and chronic adaptation is non-existent. Assuming evidence was provided to indicate PAP could be exploited for the achievement of chronic adaptation, widespread use would likely be impractical for many of the same reasons PAP is impractical in the enhancement of acute performance.

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Appendix B: Raw Data

Table 1

Mean (SD) VJH (cm) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (cm)	2 (cm)	3 (cm)	4 (cm)
M	61.08	61.12	60.58	60.11
SD	(8.98)	(9.75)	(8.46)	(6.95)

Table 2

Mean (SD) VJH (cm) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (cm)	2 (cm)	3 (cm)	4 (cm)
M	61.61	61.66	60.90	60.29
SD	(9.22)	(8.88)	(9.37)	(8.51)

Table 3

Mean (SD) PP (W) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (W)	2 (W)	3 (W)	4 (W)
M	4523.16	4802.93	4652.47	4394.29
SD	(1150.95)	(1306.24)	(1124.74)	(1119.61)

Table 4

Mean (SD) PP (W) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (W)	2 (W)	3 (W)	4 (W)
M	4644.67	4423.46	4370.12	4353.57
SD	(1127.74)	(1025.04)	(961.33)	(962.57)

Table 5

Mean (SD) PA (m/s/s) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (m/s/s)	2 (m/s/s)	3 (m/s/s)	4 (m/s/s)
M	15.35	15.93	15.65	15.41
SD	(1.55)	(1.61)	(2.23)	(2.12)

Table 6

Mean (SD) PA (m/s/s) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (m/s/s)	2 (m/s/s)	3 (m/s/s)	4 (m/s/s)
M	16.00	15.69	15.85	15.59
SD	(1.67)	(1.75)	(1.60)	(1.64)

Table 7

Mean (SD) PF (N) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (N)	2 (N)	3 (N)	4 (N)
M	1324.08	1354.50	1328.62	1324.85
SD	(200.83)	(202.45)	(232.23)	(264.39)

Table 8

Mean (SD) PF (N) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (N)	2 (N)	3 (N)	4 (N)
M	1378.50	1355.81	1369.40	1329.34
SD	(191.73)	(203.17)	(217.39)	(192.88)

Table 9

Mean (SD) RPF (N/s) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (N/s)	2 (N/s)	3 (N/s)	4 (N/s)
M	15296.83	16293.61	14484.93	15124.26
SD	(2310.51)	(2990.34)	(2098.89)	(2713.27)

Table 10

Mean (SD) RPF (N/s) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (N/s)	2 (N/s)	3 (N/s)	4 (N/s)
M	15737.87	16872.34	15970.75	14990.53
SD	(2033.68)	(2607.05)	(3092.39)	(2889.89)

Table 11

Mean (SD) PV (m/s) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (m/s)	2 (m/s)	3 (m/s)	4 (m/s)
M	3.60	3.71	3.69	3.70
SD	(0.26)	(0.32)	(0.31)	(0.23)

Table 12

Mean (SD) PV (m/s) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (m/s)	2 (m/s)	3 (m/s)	4 (m/s)
M	3.64	3.59	3.61	3.57
SD	(0.27)	(0.26)	(0.26)	(0.31)

Table 13

Maximal (SD) VJH (cm) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (cm)	2 (cm)	3 (cm)	4 (cm)
M	65.83	67.67	65.79	65.76
SD	(8.56)	(7.34)	(8.32)	(9.14)

Table 14

Maximal (SD) VJH (cm) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (cm)	2 (cm)	3 (cm)	4 (cm)
M	65.91	66.16	66.05	65.96
SD	(10.07)	(9.05)	(8.91)	(9.06)

Table 15

Maximal (SD) PP (W) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (W)	2 (W)	3 (W)	4 (W)
M	4635.75	4913.88	4920.12	4888.27
SD	(1140.71)	(1256.90)	(1186.02)	(1099.76)

Table 16

Maximal (SD) PP (W) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (W)	2 (W)	3 (W)	4 (W)
M	4924.93	4802.30	4694.44	4689.17
SD	(1202.86)	(1128.76)	(1025.84)	(1040.40)

Table 17

Maximal (SD) PA (m/s/s) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (m/s/s)	2 (m/s/s)	3 (m/s/s)	4 (m/s/s)
M	16.25	16.42	16.42	16.37
SD	(1.30)	(1.51)	(2.19)	(2.06)

Table 18

Maximal (SD) PA (m/s/s) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (m/s/s)	2 (m/s/s)	3 (m/s/s)	4 (m/s/s)
M	16.87	16.80	16.86	16.73
SD	(1.44)	(1.54)	(1.43)	(1.44)

Table 19

Maximal (SD) PF (N) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (N)	2 (N)	3 (N)	4 (N)
M	1394.92	1404.98	1401.17	1393.06
SD	(157.29)	(182.67)	(246.21)	(218.21)

Table 20

Maximal (SD) PF (N) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (N)	2 (N)	3 (N)	4 (N)
M	1454.33	1433.50	1432.79	1427.61
SD	(162.58)	(184.10)	(179.90)	(175.10)

Table 21

Maximal (SD) RPF (N/s) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (N/s)	2 (N/s)	3 (N/s)	4 (N/s)
M	17119.94	18186.85	17948.97	17576.84
SD	(2791.30)	(3233.13)	(3173.22)	(2993.21)

Table 22

Maximal (SD) RPF (N/s) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (N/s)	2 (N/s)	3 (N/s)	4 (N/s)
M	18032.48	17810.12	17718.03	18005.40
SD	(3222.94)	(3621.51)	(3153.03)	(2938.93)

Table 23

Maximal (SD) PV (m/s) for jump sets 1 to 4 in Testing Protocol 1 (n=16).

	1 (m/s)	2 (m/s)	3 (m/s)	4 (m/s)
M	3.87	4.01	3.93	3.93
SD	(0.23)	(0.26)	(0.37)	(0.23)

Table 24

Maximal (SD) PV (m/s) for jump sets 1 to 4 in Testing Protocol 2 (n=16).

	1 (m/s)	2 (m/s)	3 (m/s)	4 (m/s)
M	3.81	3.83	3.84	3.81
SD	(0.28)	(0.28)	(0.24)	(0.26)

Table 25

<u>Maximal (SD) MVIC (N) Performed in Testing Protocol 1 (n=16).</u>

	1 (N)	2 (N)	3 (N)
<u>M</u>	1387.49	1402.37	1314.8
<u>SD</u>	149.61	173.22	185.28

Appendix C: Statistical Analysis

Table 26

Repeated Measures (Two-Way Within Subjects) Multivariate Analysis of Variance for Trials, Time and Trials*Time for Mean Values (n=16).

Within Subjects Effect	F	P
Trials	4.230	0.022
Time	1.505	0.101
Trials*Time	1.945	0.019

Table 27

Repeated Measures (Two-Way Within Subjects) Multivariate Analysis of Variance for Trials, Time and Trials*Time for Maximal Values (n=16).

Within Subjects Effect	F	P
Trials	3.465	0.074
Time	0.845	0.644
Trials*Time	1.482	0.152

Table 28

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Mean Values for VJH (n=16).

Within Subjects Effect	F	P
Trials	0.184	0.674
Time	1.347	0.271
Trials*Time	0.022	0.995

Table 29

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Mean Values for PP (n=16).

Within Subjects Effect	F	P
Trials	5.128	0.039
Time	2.439	0.077
Trials*Time	2.576	0.066

Table 30

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Mean Values for PA (n=16).

Within Subjects Effect	F	P
Trials	1.074	0.316
Time	2.867	0.047
Trials*Time	3.785	0.017

Table 31

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Mean Values for PF (n=16).

Within Subjects Effect	F	P
Trials	1.800	0.200
Time	0.896	0.450
Trials*Time	1.050	0.380

Table 32

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Mean Values for RPF (n=16).

Within Subjects Effect	F	P
Trials	3.513	0.080
Time	1.631	0.196
Trials*Time	0.907	0.445

Table 33

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Mean Values for PV (n=16).

Within Subjects Effect	F	P
Trials	4.424	0.018
Time	0.799	0.501
Trials*Time	3.500	0.017

Table 34

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Maximal Values for VJH (n=16).

Within Subjects Effect	F	P
Trials	0.262	0.616
Time	1.509	0.225
Trials*Time	1.108	0.356

Table 35

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Maximal Values for PP (n=16).

Within Subjects Effect	F	P
Trials	1.310	0.270
Time	1.551	0.214
Trials*Time	2.380	0.093

Table 36

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Maximal Values for PA (n=16).

Within Subjects Effect	F	P
Trials	6.236	0.025
Time	0.194	0.900
Trials*Time	0.347	0.792

Table 37

Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Maximal Values for PF (n=16).

Within Subjects Effect	F	P
Trials	6.006	0.027
Time	0.415	0.743
Trials*Time	0.607	0.614

Table 38

<u>Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Maximal Values for RPF (n=16).</u>

Within Subjects Effect	F	P
Trials	1.181	0.294
Time	0.872	0.463
Trials*Time	1.020	0.393

Table 39

<u>Repeated Measures (Two-Way Within Subjects) Univariate Analysis of Variance for Trials, Time and Trials*Time for Maximal Values for PV (n=16).</u>

Within Subjects Effect	F	P
Trials	3.572	0.078
Time	0.852	0.473
Trials*Time	3.358	0.027

Table 40

Correlations Between Strength (Absolute and Relative) and Mean Values for the Six Dependent Variables (two-tailed, p=0.01)

	VJH	PP	PA	PF	RPF	PV
Absolute strength	0.377	0.499	0.692*	0.583	0.277	0.339
Relative Strength	0.452	0.297	0.483	0.469	0.161	0.133

* Significant at p=0.01

Table 41

Correlations Between Strength (Absolute and Relative) and Maximal Values for the Six Dependent Variables (two-tailed, p=0.01)

	VJH	PP	PA	PF	RPF	PV
Absolute strength	0.248	0.586	0.533	0.510	0.083	0.582
Relative Strength	0.209	0.363	0.327	0.302	0.030	0.389

Appendix D: Informed consent

The effect of loading on the enhancement of depth jumps (DJ) over three consecutive trials

You are being invited to voluntarily participate in a study entitled "The effect of loading on the enhancement of depth jumps (DJ) over three consecutive trials" that is being conducted by Dan Robbins, a graduate student, in the department of Physical Education at the University of Victoria. As a graduate student, I am required to conduct research as part of the requirements for a degree in Sport and Exercise Studies. It is being conducted under the supervision of Dr. David Docherty. If you have any questions or concerns, you may contact myself at 595-3053 or my supervisor at 721-8375, or you may contact the Associate Vice-President, Research at 472-4362.

Your participation in this research is completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you withdraw from the study, your data will not be used in the analysis.

The purpose of this research project is to examine the effects of performing a 10-second maximal voluntary isometric contraction(MVIC) four minutes prior to performing a set of five depth jumps over three consecutive trials.

Research of this type is important because it will help us to understand how best to develop training programs

You are being asked to participate in this study because you are well-trained and involved in a power sport (e.g. basketball or volleyball) or because in the half squat exercise your one repetition maximum (1-RM) is at least 2 times your body weight or because your 1-RM is less than 1 times your body weight. Subject will be divided into these three groups: Power, high strength and low strength.

If you agree to voluntarily participate in this research, your participation will include attendance at three sessions lasting between 30-60 minutes. You will be asked to provide your age and body weight. You will be asked to perform three sets of three 6-second maximal voluntary isometric (muscles do not move) contractions and six sets of 5 counter movement jumps.

Participation in this study may cause some inconvenience to you, including spending a total of almost three hours in the Sport and Fitness Testing Center.

There are no known or anticipated risks, greater than normal training, to you by participating in this research. That is, above those risks attached to performing MVICs or counter movement jumps in any strength or power routine.

The potential benefits of your participation in this research include include determining if power can be enhanced by pre-loading with three 6-second MVICs. This study will also help to clarify any benefits of the complex training method.

Your confidentiality and the confidentiality of the data will be protected by assigning a code number to your data sheet rather than your name. Only the principal investigator and the supervising professor will have access to the data.

Data from this study will be stored for five years under lock and then disposed of by shredding.

It is anticipated that the results of this study will be shared with others through a thesis paper and journal publication.

In addition to being able to contact the researcher and the supervisor at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4362).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

Name of Participant	*Signature*	*Date*

A copy of this consent will be left with you, and a copy will be taken by the researcher.

VITA

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Title of Thesis:

The Effect of Loading on the Enhancement of Counter Movement Jumps (CMJ) over Three Consecutive Trials

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