

# USE OF LOADED CONDITIONING ACTIVITIES TO POTENTIATE MIDDLE- AND LONG-DISTANCE PERFORMANCE: A NARRATIVE REVIEW AND PRACTICAL APPLICATIONS

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## ABSTRACT

Blagrove, RC, Howatson, G, and Hayes, PR. Use of loaded conditioning activities to potentiate middle- and long-distance performance: a narrative review and practical applications. *J Strength Cond Res* 33(8): 2288–2297, 2019—The warm-up is an integral component of a middle- and long-distance athlete's preperformance routine. The use of a loaded conditioning activity (LCA), which elicits a postactivation potentiation (PAP) response to acutely enhance explosive power performance, is well researched. A similar approach incorporated into the warm-up of a middle- or long-distance athlete potentially provides a novel strategy to augment performance. Mechanisms that underpin a PAP response, relating to acute adjustments within the neuromuscular system, should theoretically improve middle- and long-distance performance through improvements in submaximal force-generating ability. Attempts to enhance middle- and long-distance-related outcomes using an LCA have been used in several recent studies. Results suggest that benefits to performance may exist in well-trained middle- and long-distance athletes by including high-intensity resistance training (1–5 repetition maximum) or adding load to the sport skill itself during the latter part of warm-ups. Early stages of performance seem to benefit most, and it is likely that recovery (5–10 minutes) also plays an important role after an LCA. Future research should consider how priming activity, designed to enhance the  $\dot{V}O_2$  kinetic response, and an LCA may interact to affect performance, and how different LCAs might benefit various modes and durations of middle- and long-distance exercises.

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## INTRODUCTION

Middle- (2–10 minutes) and long-distance (>10 minutes) performance are typically considered to be limited by physiological factors such as maximal oxygen uptake ( $\dot{V}O_{2max}$ ), movement economy, and fractional utilization of  $\dot{V}O_{2max}$  (14,62). However, neuromuscular factors are also known to contribute (14,71). To acutely optimize middle- and long-distance performance, it is well established that an active warm-up should be included in an athlete's preparation routine (10). Research has tended to focus on “priming” strategies, involving high-intensity intermittent or continuous exercise designed to induce specific cardiovascular and metabolic adjustments, which subsequently augment the oxygen uptake ( $\dot{V}O_2$ ) kinetic response during the early stages of exercise and thus performance outcomes (4,18,19,50).

Conversely, for athletic performances that require high levels of power production, such as jumps and sprints, a plethora of research has been conducted investigating various preconditioning stimuli designed to potentiate the neuromuscular system and enhance performance in these tasks (59,78,92). Although it is well established that physiological parameters and performance can benefit after a period of strength training (ST) in middle- and long-distance athletes (6,9), the possibility of using a loaded conditioning activity (LCA) to acutely enhance middle- and long-distance-related outcomes has only been explored recently (5,21,79). An LCA involves using a high-intensity resistance exercise or adding load to a movement akin to the sports skill itself, to elicit a short-term enhancement in neuromuscular function, known as postactivation potentiation (PAP). The aim of this narrative review is therefore to consider whether an LCA can provide an acute potentiation of middle- and long-distance performance from a theoretical and evidence-based perspective and provide practical recommendations for coaches. Ethical approval was not

required for our narrative review, however it was approved by Birmingham City University.

### PRIMING ACTIVITY

Studies have typically shown that a warm-up which includes a bout of high-intensity exercise (60–85% of peak power output [PPO]) lasting 3–6 minutes is sufficient to positively influence endurance performance (4,41,60). Several studies have also investigated the effects of high-intensity intermittent and single sprint approaches to enhancing performance or the  $\dot{V}O_2$  response at the onset of exercise (11,17,48,61,90). When compared with a continuous warm-up of lower intensity, a priming protocol involving  $5 \times 10$ -second near-maximal sprints (50-second recovery) have been shown to enhance kayak 2-minute time trial (TT) performance by a small (effect size [ES]: 0.2) but statistically significant margin (11). Conversely, the same protocol 5 minutes before a 3-km cycle TT had no effect on outcome and was shown to attenuate performance if sprints were completed maximally (61). Using a longer interrepetition recovery duration (5-minute) and rest period before the onset of exercise (15-minute), maximal sprints ( $3 \times 30$ -second) were shown to enhance the amplitude to which  $\dot{V}O_2$  rose during perimaximal-intensity cycle exercise by 11% (90). Similarly, the use of a single high-intensity run (200-m), performed 20 minutes before an 800-m TT, provided a significantly faster time (1.2-second) compared with a control trial, which used  $6 \times 50$ -m “strides,” typical of traditional warm-up for a middle-distance runner (48). Collectively, these results demonstrate that a high-intensity bout of priming activity can positively influence  $\dot{V}O_2$  kinetics and middle- and long-distance performance; providing the protocol does not lead to excessive fatigue caused by the interaction between exercise intensity and recovery duration.

The mechanisms that underpin an enhancement in  $\dot{V}O_2$  kinetics and performance as a result of priming activity are believed to relate to an improvement in the ability to deliver oxygen to active tissues (67) or activation of processes associated with oxidative metabolism (49). It has also been proposed that previous high-intensity exercise necessitates an increase in firing or recruitment of higher threshold motor units, which are subsequently accessible at the onset of exercise (49). This may allow a greater number of muscle fibers to share the load imposed by exercise and decrease the demand to recruit further motor units as exercise progresses. This hypothesis is supported by works that show increases in integrated electromyography (iEMG) at the onset of exercise (16) and during the latter half of intense exercise (85) after priming. Interestingly, Burnley et al. (16) observed the improvement in  $\dot{V}O_2$  kinetics during the primary component closely matched the increase in iEMG which was observed. This evidence indicates that other forms of high-intensity exercise, such as an LCA, which is capable of activating a large pool of motor units

(76), may offer an alternative means of enhancing middle- and long-distance performance.

### POSTACTIVATION POTENTIATION

Mechanistically, PAP is defined as an increase in a twitch response that follows a brief maximal voluntary contraction (MVC) caused by the phosphorylation of myosin light chains (MLCs) (47,88). Contemporary definitions of PAP encompass a range of different types of muscular contraction and tend to attribute acute improvements in a wide range of athletic performance tasks after a preconditioning stimulus to PAP (59,92). Moreover, evidence for MLC phosphorylation is somewhat weak in humans; therefore, various authors have suggested that other mechanisms may also be responsible for a PAP response, including an increase in motor unit recruitment and changes in limb stiffness (59,83). These mechanisms have been shown to facilitate a short-term improvement in neuromuscular performance that may also have utility for middle- and long-distance-related outcomes.

The efficacy of a PAP-inducing stimuli on performance in skills requiring power has been discussed in several recent reviews (38,59,92). Ballistic exercise protocols (3–5 repetitions of depth jumps, weighted jumps, and weightlifting derivatives) and heavy-resistance exercise ( $>85\%$  1 repetition maximum [RM] or 3RM) have consistently been shown to enhance (2–5%) vertical jump, sprint performance ( $\leq 100$ -m), repeated sprint ability, and change of direction speed following a recovery duration of 5–10 minutes recovery. The effect of a PAP protocol on middle- and long-distance-related outcomes has received far less attention. Given the paucity of the literature, an examination of the mechanisms that underpin a PAP response could provide clues as to whether a benefit could exist.

### Phosphorylation of Myosin Light Chains

Although PAP can be elicited in both type I and type II fibers, athletes with a higher percentage of type II fibers, and therefore greater MLC, tend to experience higher levels of potentiation (88). Studies that have demonstrated positive outcomes from an LCA on explosive performance tasks have typically used athletes from intermittent high-intensity sports or participants with a background in strength training (59,78). Furthermore, there seems to be a clear link between the strength status and the amplitude of a potentiation response (20,37). This suggests that athletes who excel in endurance-based sports, who typically possess a high proportion of type I fibers (24), might be expected to elicit a lower PAP response compared with strength-trained athletes. Despite this supposition, endurance-trained athletes are capable of eliciting a greater twitch potentiation response compared with untrained individuals after a MVC (42). Endurance training has also been shown to enhance shortening velocity of type I fibers (30,77), with a concomitant increase in MLC (77). This adaptation in the trained muscles of endurance-trained athletes has been attributed to an increased capacity for MLC

phosphorylation, which therefore increases the potential of eliciting a PAP response (42).

After a peri-MVC, fatigue, and potentiation can coexist within a muscle (58), with the magnitude of both a consequence of the nature of the contraction and the characteristics of the individual. Because of a superior resistance to fatigue in endurance-trained athletes, potentiation effects have also been shown to prevail for longer during an intermittent fatiguing task, compared with power-trained athletes (66). Potentially, therefore, despite possessing a relatively low percentage of type II fibers (and thus MLC), middle- and long-distance athletes could have the capability to amplify a PAP response in trained muscles, which may also be sufficiently long-lasting to benefit performance. In addition, it is also recognized that a PAP state provides the largest benefits during dynamic activities requiring low-frequency force outputs (39,87). These frequencies approximate the firing rates required to sustain repeated submaximal contractions (25,42), which implies that PAP could potentially be used to augment middle- and long-distance performance.

#### Motor Unit Recruitment

An LCA such as an MVC or a series of explosive dynamic contractions, require the activation of high-threshold motor units (76). During such contractions, high-frequency electrical impulses provide the input required to release large quantities of neurotransmitter at the neuromuscular junction, thus ensuring the activation of large motor units. In addition, during a conditioning activity where a muscle is stretched rapidly, such as a plyometric exercise, Ia-afferent fibers respond through the muscle spindle apparatus by transmitting high-frequency impulses to the spinal cord (51). This elicits a stretch reflex response, whereby for each parent Ia fiber, multiple synapses project action potentials to adjacent efferent  $\alpha$ -motoneurons (1). This in turn elevates output from the motoneuron pool, which can be detected as the second response to an artificially evoked contraction on an electromyography trace, known as H-wave (1). It has been shown that an induced tetanic contraction is capable of acutely elevating the transmittance of excitation potentials through the Ia afferent at the spinal cord and reduces the threshold for activation in higher-order motor units (45,57). This potentially allows a greater level of force to be developed for the same electrical input during activities that have a high reliance on the stretch-shortening cycle (SSC). Moreover, an increase in the H-wave amplitude has been observed after MVCs in the plantarflexors (40,86) and knee extensors (34) during the 5–11-minute period post-LCA. Although the evidence for enhanced motor unit recruitment after an LCA is mainly derived from studies in animal models or using artificial stimulation, it is possible that PAP could exert a beneficial effect during dynamic activities of various durations through this mechanism (75,83).

It is well established that during submaximal exercise, both PAP and fatigue are present within the muscle, and conse-

quently, PAP is believed to provide a mechanism to counteract the effects of peripheral fatigue during prolonged exercise (13,73). When this effect becomes depressed during the latter stages of exercise because of impaired excitation-contraction coupling, it has been postulated that an augmentation of the PAP response may enable the force to be maintained for longer (39,72). Similarly, as middle- and long-distance events require relatively low motor unit firing frequencies, even a small enhancement in the force delivered by the motor units should improve performance (75). Moreover, for a given intensity of submaximal exercise, a state of potentiation, which provides a more accessible pool of motoneurons, should result in motor units decreasing their firing frequency, thus delaying the onset of fatigue (42,75). A reduction in motor unit firing frequency has been shown during the early part of sustained isometric contractions without any compensatory activation of other motor units (25). It was suggested that a PAP response may partly explain this finding (25).

#### Stiffness

Stiffness refers to the ability of a body, limb, or joint to resist the application of a force (15). An increase in musculotendinous stiffness would theoretically reduce energy cost of exercise because a stiffer structure enables muscles to achieve quasi-isometric states more rapidly. This in turn influences both the magnitude and rate of shortening velocity in muscle fascicles, reducing the amount of muscular work performed (32,33). Improved musculotendinous stiffness also enables a greater contribution of mechanical work to be derived from storage and return of elastic strain energy in the Achilles tendon (74). A relationship between musculotendinous stiffness and running economy (RE) has previously been reported (2,28), and increases in tendon stiffness after a period of heavy resistance training (RT) have been shown to correlate ( $r^2 = 0.43$ ,  $p = 0.02$ ) with improvements in RE (31). Moreover, as running speed increases, tendon elastic strain energy provides a greater contribution to the work performed by the muscle-tendon unit at the ankle plantarflexors (54). Therefore, it is likely that for a well-trained middle-distance runner who operates at relatively high speeds, an enhancement in this quality would improve performance.

Higher stiffness is also related to greater concentric-dominant muscular capacity (91), which may be relevant for sports such as cycling, cross-country skiing, and swimming. Indeed, higher levels of musculotendinous stiffness have been shown to correlate with cycling speed (89), and double poling velocity in cross-country skiing (56), thus an acute improvement in this physiological attribute may provide a mechanism to enhance performance for middle- and long-distance athletes. It has also been suggested that an acute enhancement in limb stiffness may offer an additional explanation for the improvements observed in explosive activities after an LCA (59).

After an LCA is used to induce PAP, both the muscular properties and the tensile mechanisms of a musculotendinous unit are likely to be affected (35). A previous review

concluded that there was moderate evidence for decreased Achilles tendon stiffness (measured through ultrasound) after MVC; however, activities involving a SSC, such as running and hopping, have minimal effect (69). A subsequent investigation observed a PAP response without alteration in tendon stiffness after a single 6-second MVC (35), demonstrating that fatigue may be an important factor modulating short-term changes in stiffness. It seems therefore that the direction and the extent of alterations in stiffness after an LCA are influenced by the mode and dosage of the exercise used (69). Tendons in particular seem to be more resistant to fatigue during conditioning activities that use the SSC. This has implications when examining the efficacy of such strategies on middle- and long-distance disciplines that rely heavily on musculotendinous stiffness.

Assessing changes in tendon structures provides 1 perspective on stiffness; however, changes in vertical or limb stiffness may be the consequence of morphological alterations in other tissues or segments. Leg stiffness and ground contact time during a drop jump task performed on a sledge was shown to be positively affected after a set of back squats at 93% of 1RM in elite rugby players (22). Similarly, Moir et al. (65) found improvements in vertical stiffness during a counter-movement jump after 3 back squat repetitions at 90% 1RM in female volleyball players. In contrast to the aforementioned studies, these results indicate that an LCA may provide a suitable stimulus to acutely enhance leg and vertical stiffness during activities that require the SSC, such as distance running. Moreover, leg stiffness has been shown to decrease with fatigue in runners (44); therefore, an increase in stiffness at the onset of exercise may offset this reduction.

## EXPERIMENTAL EVIDENCE

The foregoing discussion suggests that the inclusion of an LCA within the warm-up routine of middle- and long-distance athletes could augment subsequent performance outcomes. Only 4 studies have attempted to examine this conjecture experimentally (Table 1), yielding mixed results. Two studies have investigated the effect of heavy-resistance exercise on middle- (29) and long-distance (79) performance. Silva et al. (79) found an improvement ( $-6.1\%$ ,  $p = 0.02$ ,  $ES = 0.38$ ) in 20-km TT performance in well-trained cyclists after 4 sets of 5RM on a leg press. The authors attributed the improvement to an increase ( $5.8\%$ ) in mean power during the first 2 km of the test, as little difference was observed across other split times. Similarly, Feros et al. (29) used 5  $\times$  5-second isometric contractions on a rowing ergometer to successfully enhance the first 500 m of a 1-km TT performance in elite international rowers ( $-1.9\%$ ,  $p = 0.009$ ,  $ES = 0.62$ ); however, an improvement in 1-km TT performance was not noted compared with the control trial. Both studies found no change in perceived exertion between trials, which is believed to regulate effort during endurance performance (80).

This suggests that potentiation in the neuromuscular system allowed a greater amount of power to be developed during the first few minutes of exercise for the same level of effort. It therefore appears that an LCA could be beneficial for the early stages of a middle- or long-distance TT effort; however, it is unclear whether the potentiating starting speed facilitates an improvement in overall performance.

Barnes et al. (5) used 6 sprints wearing a weighted vest (20% body mass [BM]) to achieve beneficial effects to RE ( $-6.0\%$ ,  $ES = 1.40$ ) and peak running speed ( $2.9\%$ ,  $ES = 0.35$ ) in a group of well-trained distance runners. The authors observed a very high correlation ( $r = -0.88$ ) between changes in peak speed and changes in leg stiffness. Evidence for individual responses to the LCA were also present. The acute improvements achieved in RE in this study are of a similar magnitude to those achieved following a 8–14 weeks explosive ST intervention (8,64,71), and are likely to be sufficient to provide a performance benefit (46). Recently, Chorley and Lamb (21) used a similar protocol in a group of highly-trained cyclists. Prior to a 4-km time-trial, participants performed three 10-second loaded sprints (70% PPO) at a low cadence (60-revolutions per minute). The results showed a small ( $ES = 0.2-0.3$ ) and non-significant ( $p > 0.05$ ) change in completion times, mean power output and mean peak force, however the authors suggested that the improvements were meaningful in the context of smallest worthwhile effect values (21). A statistically significant increase in  $\dot{V}O_2$  during the first 1.5-km ( $6.8\%$ ,  $ES = 0.97$ ) perhaps indicates an enhancement in rate adjustment of the oxidative system, or again, a potentiation effect benefited the initial stages of exercise.

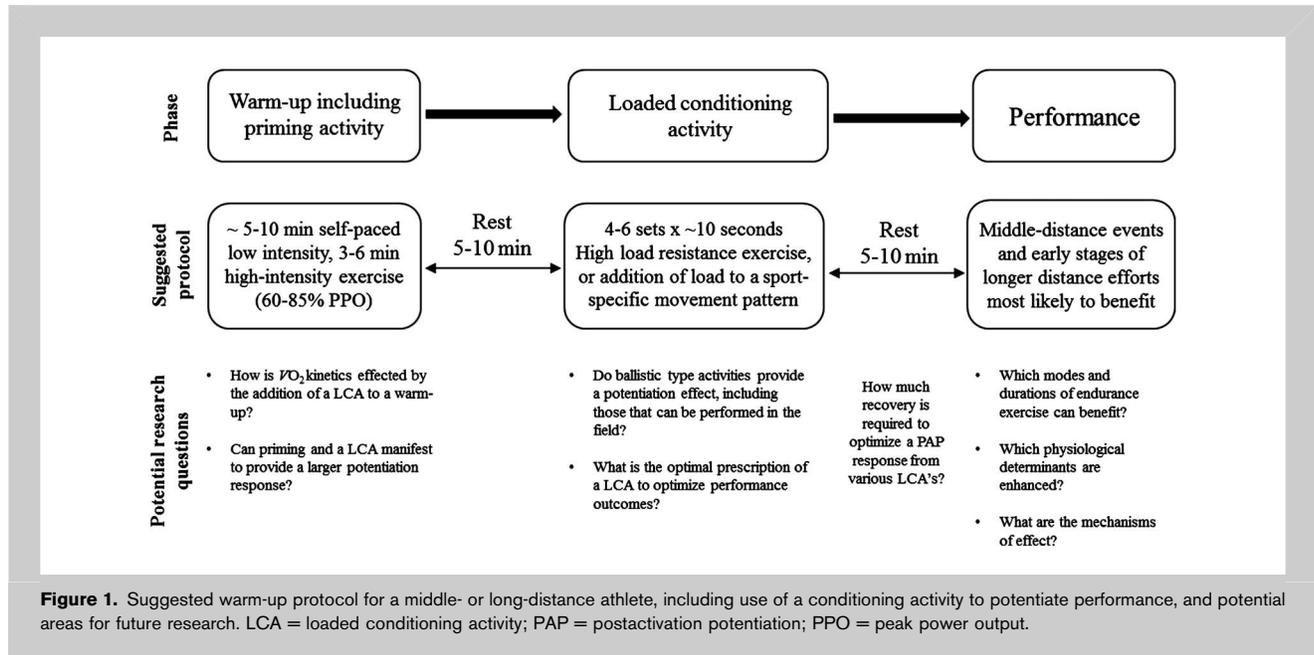
## PRACTICAL APPLICATIONS AND MODULATING FACTORS

A PAP response is modulated by a number of variables that each require consideration to ensure a performance benefit is optimized. These factors have been reviewed extensively for short-duration athletic performance (59,78), however recommendations should be examined for appropriateness in the context of middle- and long-distance performance. Based upon the available evidence, Figure 1 provides a suggested warm-up protocol that middle- and long-distance athletes could adopt to enhance their performance. There is convincing evidence that following an initial low intensity warm-up, pre-performance preparation should include a higher intensity priming component (e.g., 3–6 minutes at 60–85% PPO) to facilitate the  $\dot{V}O_2$  kinetic response during the early stages of exercise (4,41,60). Following a 5–10 minutes passive recovery from this aerobic phase of warm-up, a performance advantage is likely to be gained by including either near maximal intermittent sprints (4 to 6  $\times$  ~10-second) or an LCA designed to elicit a PAP response. Based upon the experimental evidence to date, it is likely that a PAP response will only be realized under a specific set of circumstances.

**TABLE 1.** Summary of studies that have investigated the acute effects of a loaded conditioning activity on variables related to performance in middle- and long-distance athletes.\*

| Authors               | Participants     | Sport            | Training status                                                                                                      | Potentiation protocol                                    | Recovery | Performance protocol                                              | Main findings compared with control condition                                                                                                                                                                 |
|-----------------------|------------------|------------------|----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|----------|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Barnes et al. (5)     | 11 male          | Distance runners | Well-trained ( $\dot{V}O_2\text{max}$ $62.1 \pm 5.9$ mL·kg <sup>-1</sup> ·min <sup>-1</sup> , 5 km 16.0 ± 1.0 min)   | 6 × 10 s weighted vest (20% BM) sprints ~1,500 m pace    | 10 min   | 5 min run @14 km·h <sup>-1</sup> , incremental test to exhaustion | RE: -6.0% (ES = 1.40), peak running speed 2.9% (ES = 0.35), % $\dot{V}O_2\text{max}$ -7.2% (ES = 0.68)                                                                                                        |
| Chorley and Lamb (21) | 10 male          | Cyclists         | Highly-trained ( $\dot{V}O_2\text{max}$ $65.3 \pm 5.6$ mL·kg <sup>-1</sup> ·min <sup>-1</sup> , 8.2 ± 6.0 y cycling) | 3 × 10 s @70% PP, 60 rpm (30 s recovery)                 | 5 min    | 4 km Wattbike TT                                                  | TT: -0.5% (ES = 0.26), mean power (ES = 0.24), mean force (ES = 0.21) all NSS. 0-1.5 km $\dot{V}O_2$ : 6.8% ( $p \leq 0.05$ , ES = 0.97). 4 km TT $\dot{V}O_2$ : 2.4% ( $p \leq 0.05$ , ES = 0.28)            |
| Feros et al. (29)     | 9 male, 1 female | Rowers           | Elite ( $\dot{V}O_2\text{max}$ $68.7 \pm 3.1$ mL·kg <sup>-1</sup> ·min <sup>-1</sup> , >5 y RT history)              | 5 × 5 s (15 s recovery) isometric CC on rowing ergometer | 4 min    | 1 km rowing ergometer TT                                          | 0-500 m TT split: -1.9% ( $p = 0.009$ , ES = 0.62), 0-500 m TT power: 6.6% ( $p = 0.007$ , ES = 0.64). 1 km TT (ES = 0.21), mean power (ES = 0.26) both NSS                                                   |
| Silva et al. (79)     | 11 male          | Cyclists         | Well-trained ( $\dot{V}O_2\text{peak}$ $56.7 \pm 6.7$ mL·kg <sup>-1</sup> ·min <sup>-1</sup> , 2-10 y running)       | 4 × 5RM leg press                                        | 10 min   | 20 km static cycle TT                                             | TT: -6.1% ( $p = 0.02$ , ES = 0.38). 0-2 km mean power: 5.8% ( $p = 0.06$ , ES = 0.22); 2-18 km (2.7%) and 18-20 km (0.8%) both NSS. Mean power (ES = 0.11), $\dot{V}O_2$ (ES = 0.19), BL (ES = 0.13) all NSS |

\*BM = body mass; RE = running economy; ES = effect size; PP = peak power; rpm = revolutions per minute; TT = time trial; NSS = no statistical significance ( $p \leq 0.05$ ); RT = resistance training; CC = conditioning contractions; RM = repetition maximum; BL = blood lactate.



### Participant Characteristics

As discussed, type II muscle fibers have a greater affinity for a PAP response (42), thus endurance-trained individuals, who typically possess a low percentage of type II fibers (24,81), are less likely to benefit from an LCA compared to strength-trained athletes. It is likely therefore, that middle-distance competitors, who possess a more even split of fiber phenotypes (23) might benefit from a warm-up that includes an LCA more-so than a long-distance athlete. It is also possible that older endurance athletes have a lower capacity to generate a PAP response as age-related reductions in muscle mass have been attributed to smaller type II fiber size (68).

As expected, strength-trained athletes tend to exhibit a larger PAP response (ES = 0.53) than athletes with no ST experience (ES = 0.07) irrespective of strength-level (78). It has been reported that well-trained rowers and swimmers regularly utilize ST as part of their training routine (3,55), and highly-trained distance runners include ST modalities more so than recreational runners (12). The well-trained runners, cyclists and rowers in the studies that observed an improvement in performance following an LCA had ST experience (5,29,79), therefore it appears that possessing a background in ST may be important to ensure an LCA is beneficial. Furthermore, highly-trained endurance athletes are capable of eliciting an amplified PAP response, the extent of which appears closely related to the training status of the limb exposed to the LCA (42,66). It seems that training status per se, may therefore be as important as ST experience when considering the type of athlete who may benefit from an LCA. This could be attributed to an athletes skill level on an LCA, as better inter-muscular co-ordination on a task is likely to enable higher threshold motor units to

be activated (7). In this regard, it may therefore be possible that a learning-effect exists, whereby middle- and long-distance athletes with less ST experience are able to benefit from an LCA following a number of exposures to a PAP-type protocol. Further investigation is required to confirm this conjecture.

### Loaded Conditioning Activity

A recent meta-analysis indicated that plyometric and high-load RT provide a similar PAP response (ES: 0.41 and 0.47 respectively), whereas moderate load exercises and isometric contractions produce a negligible effect (ES: <0.2) on tasks requiring short bursts of explosive power (78). Results from the studies on middle- and long-distance performance (Table 1) corroborate this finding. Silva et al. (79) observed an improvement (-6.1%, ES: 0.38) in 20-km cycling performance following 5RM leg pressing, and 1-km rowing performance was unaltered by a series of 5 x 5-second isometric contractions (29). No studies to date have attempted to use a traditional plyometric exercise to elicit a PAP response in endurance athletes. However Barnes et al. (5) added load (20% body mass) to sprints (6 x 10-second) and achieved improvements in RE (-6.0%, ES: 1.40), peak running speed (2.9%, ES: 0.35) and  $\dot{V}O_2$ max (-7.2%, ES = 0.68).

When attempting to exploit PAP to enhance performance, a sufficiently high-intensity LCA is required to induce potentiation, however this also produces a high-level of fatigue. A recent review provides evidence for impairments in endurance-related performance for up to 72-hour following a single bout of RT (27). Obviously performing multiple exercises or high load volumes will generate a level of neuromuscular fatigue that is likely to adversely affect a bout of

endurance exercise performed immediately after. However, several studies have observed high levels of fatigue generated from a prescription that is not excessively different to the studies reviewed (26,63,82). For example, Michaut et al. (63) found reduced twitch activation from 2-minute to 48-hour following 5-sets of 10 eccentric contractions. Although it appears that multiple sets and a low number of repetitions of an LCA optimize a PAP response, the effect is mediated by both strength-level and exercise intensity (78,92). It is likely that athletes who lack ST experience will develop higher levels of fatigue compared to those who are familiar with LCA-type exercises, however the enhanced fatigue resistance of endurance-trained athletes means they display similar recovery profiles to strength-trained individuals (66). Thus a relatively low volume ( $\leq 6\text{-sets} \times 3$  to 5 repetitions or  $\sim 10\text{-second}$ ) of sub-maximal contractions is most likely to yield a beneficial response (59,78). Further research is warranted to ratify this suggestion.

A limitation of many PAP inducing techniques is the requirement for heavy and expensive equipment, which cannot be easily accessed in a field-based setting or prior to competition. Having the option to elicit a PAP response without the need for specialist equipment or facilities would be of considerable practical benefit for endurance athletes and their coaches. Thus, there is appeal in protocols that add additional load to sport-specific movement patterns using portable inexpensive strategies (5,29). Plyometric-based exercise may also provide an effective means of achieving a PAP outcome, however this is yet to be determined in middle- and long-distance athletes.

#### Recovery Following Loaded Conditioning Activity

The recovery time between an LCA and the outcome activity is crucial to ensuring fatigue has dissipated sufficiently yet a state of potentiation in the neuromuscular system remains (92). This presents a dilemma, which several studies have attempted to resolve by investigating the time course of the decay in PAP and fatigue to identify the optimal window of time where the net gain from potentiation is highest (36,52,53). Passive rest intervals of between 5 and 12 minutes after heavy resistance activities (38,78,92) and 1–6 minutes following a ballistic exercise (59) have been suggested to enhance a short duration task. However, the temporal profile of a PAP response is also modulated by training status. Although weaker individuals appear to require longer ( $>8\text{-minute}$ ) recovery periods to realize a PAP response, aerobic fitness is related to an ability to recover from high-intensity exercise (84). Benefits to the early part of middle-distance efforts have been shown using a recovery duration of 4–5 minutes in endurance-trained athletes (21,29), however overall performance did not benefit from this scenario, perhaps suggesting some residual fatigue caused by the LCA was still present. Depending upon the activity utilized to induce PAP, it is therefore likely that a recovery period of between 5 and 10 minutes should be

adopted to maximize the likelihood of middle- and long-distance performance being enhanced.

#### Outcome Activity

A PAP response is transient and appears to provide negligible effects on power performance beyond approximately 12-minute post-LCA (38,92), but prevails for longer in endurance-trained athletes compared to power-trained individuals (66,70). This indicates that if long-distance athletes benefit from a PAP response, it would be likely to affect only the initial part of a performance. It may also be the case that middle-distance performances lasting  $<3$  minutes might gain more benefit compared with longer distance efforts. Studies that have used high-intensity sprinting as part of a warm-up lend support to this notion because improvements in swimming, running, and kayak performance lasting 1–2 minutes have been demonstrated (11,43,48).

Studies to date have tended to focus on measuring TT performance (21,29,79), which provides a high level of ecological validity. Assessment of movement economy and efficiency, which have been shown to benefit from chronic exposure to ST (6,9) are also likely to benefit from acute potentiation of the neuromuscular system. Preliminary evidence is contradictory in this regard as Barnes et al. (5) observed large improvements in RE after a series of weighted vest sprints, whereas Silva et al. (79) found no change in  $\dot{V}O_2$  during a 20-km cycle TT. The discrepancy is likely due to the intensities used to assess economy in these 2 articles; therefore, future work should use a common relative intensity (below lactate threshold) in participants.

#### SUMMARY AND FUTURE RESEARCH

Warm-ups are commonplace in the preperformance routine of middle- and long-distance athletes with most research focusing on the  $\dot{V}O_2$  kinetic response to various priming protocols. Over a decade ago, authors speculated that a PAP response evoked by an LCA included within an endurance athlete's warm-up routine would provide a benefit to performance (42,75). This was based on the argument that PAP has its greatest effect during activities that require motor units to fire at relatively low force frequencies. However, despite an abundance of literature studies investigating the acute effects of an LCA on subsequent ballistic performance tasks, only recently have studies emerged that have investigated the PAP phenomenon in middle- and long-distance athletes. Despite the limited number of studies that have been conducted in this area to date, the tentative conclusion is that well-trained middle- and long-distance athletes are likely to obtain some benefit, particularly during the early stages of a performance, by including an LCA in their warm-up routine.

It is recommended that middle- and long-distance athletes experiment with a warm-up protocol (Figure 1) that involves a 5–10-minute self-paced warm-up at a low intensity ( $\sim 60\%$  maximum heart rate or 40–60% PPO)

followed 5–10 minutes later by an LCA. It is likely that a short bout of high-load resistance exercise (4–6 sets × 5RM) or series of sprint efforts (4–6 sets × ~10-second), which include the addition of a light-moderate load will elicit a PAP response. A recovery of 5–10 minutes should be permitted after the LCA to ensure that fatigue has dissipated sufficiently to realize a benefit to performance.

Given the dearth of literature in this area, there is scope for a future research to address a number of important questions concerning the efficacy of PAP protocols in middle- and long-distance athletes (Figure 1). There is good evidence for including high-intensity sprints to enhance  $\dot{V}O_2$  kinetics; however, a PAP-inducing LCA may also benefit the initial stages of performance through different mechanisms. It is unknown whether a combination of these approaches (priming and LCA) would augment performance to an even greater extent, or in fact produce excessive fatigue that attenuates performance. There is also a need to explore the value of different LCAs including heavy-resistance exercise, plyometrics, and loading of the sport-skill itself. If indeed an LCA provides a benefit to middle- and long-distance performance, the optimal prescription to maximize a PAP response should also be investigated. Based on the current literature, it seems that an LCA may provide a performance advantage during the first few minutes of exercise; however, it is currently unknown whether this effect could be longer lasting or whether other determinants of performance are also affected favorably. At present, very few studies have investigated whether an LCA could positively impact subpopulations of middle- and long-distance athletes such as females and different age groups. A young group of high-performing middle-distance athletes represent an intriguing group to investigate because it is likely that they would possess a higher proportion of type II fibers compared with their more experienced senior counterparts (93). Finally, the mechanisms underlying how an LCA may positively affect middle- and long-distance performance remain speculative, thus future work in this area should also attempt to address this gap in knowledge.

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