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Does anaerobic speed reserve influence post-activation performance enhancement in endurance runners?

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Abstract

We investigated the influence of anaerobic speed reserve (ASR) on post-activation performance enhancement (PAPE). Twenty-two endurance runners and triathletes were evaluated for maximum sprinting speed (MSS) and countermovement jump (CMJ) before (non-fatigued) and after (fatigued) an incremental running test. They were allocated in LASR (low-ASR) and HASR (high-ASR) groups for comparisons between conditions. HASR showed greater CMJ and MSS (both $p \leq 0.005$) performances, with enhanced CMJ in fatigued condition ($p \leq 0.008$). Significant correlations were found between ASR, CMJ, and MSS in both conditions ($p \leq 0.01$) for the entire sample, and between ΔCMJ and ΔMSS ($p \leq 0.001$) in LASR. Our results show that ASR profile influences PAPE.

Key words: fatigue, vertical jump, maximum sprinting speed, maximum aerobic speed, endurance training, running

Introduction

It is well known that improving athlete's muscle power through strength training increases endurance performance (Beattie et al. 2014). Previously, it has been reported an enhanced neuromuscular response (i.e., countermovement jump, CMJ) in endurance athletes after a fatiguing running test (Boullosa et al. 2011). This response has been associated with the co-existence of post-activation performance enhancement (PAPE) and peripheral fatigue within the muscle (Márquez et al. 2023) and it has been proposed that the PAPE response after running is specific for endurance-trained athletes (Boullosa et al. 2011; Moré et al. 2023). Additionally, PAPE may have a role for enhancing muscle performance during endurance events by counteracting the effects of fatigue (Del Rosso et al. 2016), thus contributing to runners resilience (Jones 2023).

The term anaerobic speed reserve (ASR) is typically defined as the difference between maximal sprinting speed (MSS) and the maximum aerobic speed (MAS) (Blondel et al. 2001), although any significant anaerobic energy contribution starts above the critical speed (CS). Subsequently, latest evidence has confirmed the practicality of ASR for high-intensity exercise prescription above MAS (Sandford and Stellingwerff 2019; Sandford et al. 2019; Bok et al. 2023; Thron et al. 2024). It has been demonstrated that ASR-based exercise prescription leads to reduced interindividual variation of different physiological and perceptual responses (Julio et al. 2020; Bok et al. 2023; Thron et al. 2024). In this regard, it has been also suggested that a lower percent of ASR for a training session could prevent an excessive peripheral physiological disturbance, thus sparing the anaerobic capacity and the neuromuscular function (Bundle et al. 2003; Buchheit et al. 2012). In other words, the lower the use of ASR, the greater the exercise tolerance (Sandford and Stellingwerff 2019). Moreover, it was previously reported that individuals with low ASR exhibit a faster heart rate recovery after aerobic and anaerobic tests (Del Rosso et al. 2017). Consequently, if ASR can actually have an impact on acute neuromuscular (i.e., peripheral) and cardiovascular (i.e., central) responses, it could be also expected that it may have an influence on the balance between potentiation and fatigue after fatiguing endurance exercises. However, there are no studies comparing PAPE responses between endurance athletes with different ASR profiles. Therefore, the aim of the current study was to assess the neuromuscular responses (i.e., jumping and sprinting) of a group of endurance athletes in two conditions (i.e., non-fatigued vs. fatigued) based on their ASR profile. It was expected that athletes with lower ASR would exhibit greater PAPE responses because of a more favorable potentiation/fatigue balance.

Table 1. Characteristics of the anaerobic speed reserve groups.

	LASR	HASR
Age (years)	24.18 ± 5.4 (20.52–27.85)	25.18 ± 6.00 (21.15–29.21)
MAS (km·h^{-1})	18.82 ± 1.33 (17.93–19.71)	19.00 ± 1.10 (18.26–19.74)
tUMTT (min)	24.36 ± 2.54 (22.65–26.07)	24.85 ± 2.40 (23.24–26.47)
HRmax (bpm)	187 ± 14 (178–197)	191 ± 7 (186–195)
[bLa] (mMol·L^{-1})	9.50 ± 2.10 (8.05–10.86)	9.7 ± 1.90 (8.42–10.98)
MSS (km·h^{-1})	27.8 ± 2.1 (26.6–29.1)	30.9 ± 1.8* (29.7–32.1)
ASR (km·h^{-1})	9.00 ± 0.93 (8.37–9.61)	11.88 ± 1.43* (10.91–12.85)

Note: Values are means ± SD (95% CI). LASR = low anaerobic speed reserve, HASR = high anaerobic speed reserve, MAS = maximum aerobic speed, tUMTT = time to complete the *Université of Montreal Track Test* (UMTT), HRmax = maximal heart rate, [bLa] = blood lactate concentration post-UMTT, MSS = maximum sprinting speed, ASR = anaerobic speed reserve, SD = standard deviation, CI = confidence interval.
*Significantly different from LASR ($p < 0.05$).

Materials and methods

Participants

Twenty-two well-trained and elite endurance runners and triathletes (36.4% women) of heterogeneous level (≥2 years of training experience, 62.8–69.1 mL·kg^{-1}·min^{-1} estimated maximum oxygen consumption -VO_{2max}-, ≥6 weekly training sessions, ≥50 km per week) volunteered to participate in this study. They were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed written consent. The study was approved by the University of A Coruña Ethics Review Committee and met all the criteria of the Declaration of Helsinki. Table 1 shows the characteristics of the subjects with respect to the ASR profile.

Procedures

Firstly, athletes performed a standardized warm-up which consisted of 10 min low-intensity running. Recording of jump performance in the non-fatigued condition was conducted 2–3 min after the warm-up and consisted of two maximal CMJ attempts, separated by at least 15 s. Performance of CMJ was assessed using a force plate (Quattro jump, Kistler, Switzerland). The highest jump was selected for further analyses. After jump evaluations, the athletes performed two maximal 20 m sprints with 2 min of recovery between attempts for MSS determination, as previously suggested (Boullosa et al. 2011). The sprints were performed with a previous acceleration on a distance freely chosen by each athlete (25–40 m) for achieving a true maximum sprinting speed over the 20 m section. The sprint time was recorded with a photocell portable system (Chronomaster, Spain). After 1–2 min of rest, the athletes performed a progressive maximal running test (Université of Montreal Track Test, UMTT) to assess MAS and to induce exhaustion for evaluation of CMJ and MSS in fatigued condition. The UMTT was carried out on a 400 m synthetic track following previously described procedures (Léger and Boucher 1980; Boullosa and Tuimil 2009). Two minutes after exhaustion, the athletes completed two CMJs, and two maximal 20 m sprints at 3rd and 5th min of recovery. Figure 1 shows the study design. ASR was defined as the difference between the MSS in non-fatigued condition and the MAS determined during the UMTT.

Statistical analyses

Descriptive statistics were used to compute means and standard deviations (SDs) and 95% confidence intervals (95% CIs). The normal distribution of the variables was assessed for all groups in each condition using the Shapiro–Wilk test. Mauchly's sphericity was tested and if sphericity could not be assumed, then the Greenhouse–Geisser correction was used. Based on the median value of ASR, the sample was divided into two groups: high anaerobic speed reserve (HASR, $n = 11$) and low anaerobic speed reserve (LASR, $n = 11$), as previously suggested (Del Rosso et al. 2017; Ortiz et al. 2024; Thron et al. 2024). To evaluate the influence of ASR group on jump performance indexes and MSS between conditions, a mixed two-way Analysis of variance (2 groups × 2 conditions) was performed. Homogeneity of variance was checked using the Levene's test. In case of a significant interaction or main simple effects, post-hoc analyses with Bonferroni's pairwise comparisons were carried out to identify within- and between-group differences. Changes between conditions (i.e., Δ = non-fatigued − fatigued) were calculated and differences between groups of ASR were assessed using t tests for independent samples. Partial correlation coefficients (adjustment for ASR) were employed for analysis of the relationships between selected parameters. Cohen's d was also calculated for assessing the effect size (ES). Thresholds for ES were small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$). All statistics were performed using the IBM SPSS Statistics for Windows® (Version 20.0; Armonk, NY). The statistical significance was set at an alpha level of $p \leq 0.05$.

Results

Regarding the ASR effects on PAPE, there were no significant interactions between ASR and condition (i.e., non-fatigued vs. fatigued) neither for CMJ performance nor for MSS. There were significant main simple effects for ASR groups ($F_{[1,20]} = 20.25$, $p \leq 0.001$) and condition ($F_{[1,20]} = 8.54$, $p \leq 0.008$) regarding CMJ performance. MSS showed a significant main simple effect for ASR group ($F_{[1,20]} = 10.88$, $p \leq 0.004$) but not for condition (see Table 2). When the entire sample was considered, significant correlations were found between ASR and CMJ in non-fatigued condition ($r = 0.52$, $p \leq 0.01$), ASR and MSS in non-fatigued ($r = 0.89$, $p < 0.0001$)

Fig. 1. Study design. Chromatic scale indicates potentiation/fatigue balance. CMJ: countermovement jump; MSS: maximal sprinting speed; UMTT: Université of Montreal Track Test; tUMTT: final time in the Université of Montreal Track Test; HRmax: maximum heart rate; [bLa]: blood lactate concentration.

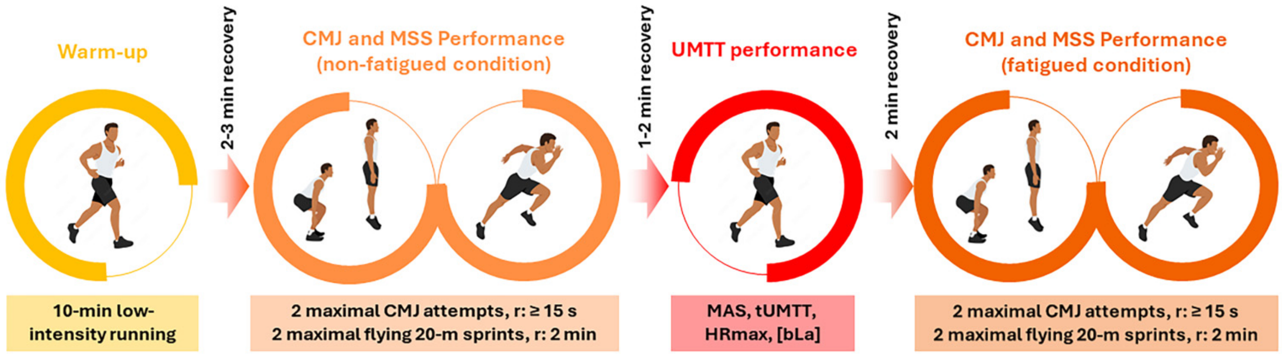


Table 2. Vertical jump performance and maximal sprinting speed for the low anaerobic speed reserve (LASR) and high anaerobic speed reserve (HASR) groups during the non-fatigued and fatigued conditions.

	LASR				HASR			
	Non-fatigued	Fatigued	Δ	ES	Non-fatigued	Fatigued	Δ	ES
CMJ height (cm)	25.6 ± 4.5 (23.2–28.0)	$27.0 \pm 4.8^{\dagger}$ (24.5–29.6)	1.4 ± 1.9	0.3	$33.4 \pm 3.1^{*}$ (31.0–35.8)	$34.1 \pm 3.3^{*\dagger}$ (31.5–36.7)	0.7 ± 1.5	0.2
MSS (km·h^{-1})	27.8 ± 2.1 (26.6–29.1)	28.0 ± 2.1 (26.7–29.4)	0.2 ± 0.7	0.1	$30.9 \pm 1.8^{*}$ (29.7–32.1)	$30.7 \pm 2.2^{*}$ (29.3–32.0)	-0.2 ± 0.8	0.1

Note: Values are means ± SD (95% CI). CMJ = Countermovement jump, MSS = maximal sprinting speed, SD = standard deviation, CI = confidence interval.
*Significantly different than LASR for the same condition (p < 0.05).
†Significantly different from the non-fatigued condition (p < 0.05).

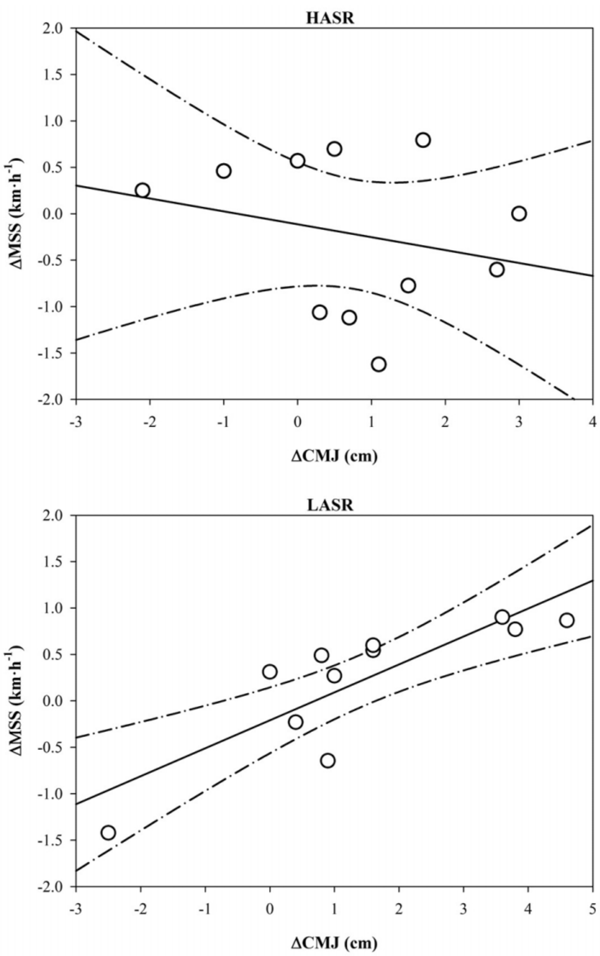
and fatigued ($r = 0.80$, $p \leq 0.0001$) conditions; MSS in non-fatigued condition and CMJ in non-fatigued ($r = 0.60$, $p \leq 0.003$) and fatigued conditions ($r = 0.61$, $p \leq 0.003$), and between MSS in fatigued condition and CMJ in fatigued condition ($r = 0.57$, $p \leq 0.006$). When each group was considered, a significant correlation between ΔCMJ and ΔMSS ($r = 0.84$, $p \leq 0.001$) was revealed only in the LASR group (see Fig. 2).

Discussion

The present study tested the hypothesis that ASR could influence PAPE responses after a maximal running test in endurance athletes as measured by CMJ and flying sprint performances. Although there was no significant interaction between ASR and condition, we found significant main simple effects for ASR groups and conditions, and a significant correlation between ASR and CMJ performance was revealed. Thus, we confirmed the influence of ASR profile on PAPE responses in endurance athletes.

Previous studies have reported an influence of ASR on the number of high-intensity interval training (HIIT) sets (Buchheit et al. 2012) and on the heart rate recovery after aerobic and anaerobic tests (Del Rosso et al. 2017), thus suggesting that a lower percent use of ASR leads to greater exercise tolerance (Sandford and Stellingwerff 2019). The present study shows that differences between ASR profiles (i.e., HASR vs. LASR) were due to different MSS, irrespective of the condition, since MAS was similar in both groups. Therefore, those runners with better anaerobic profile (i.e., HASR) expressed better sprint times and lower limbs' muscle power measured as CMJ performance. When comparing the ES between LASR and HASR groups (see Table 2), it seems that a low ASR could be associated with a greater potentiation response and a lower fatigue in both jumping and sprinting abilities. Even though this result is difficult to explain from a mechanistic perspective, it is likely that those endurance athletes with a low ASR, or with a lower MSS for a given MAS, could be more benefited for PAPE responses probably because of a better potentiation/fatigue balance after an exhausting running exercise. In other words, athletes of the HASR group who exhibited higher neuromuscular performances could present a higher fatigue after exhaustion, thus minimizing the effects of PAPE on CMJ and MSS. This rationale should be interpreted with caution, since we did not find any interaction between ASR groups and conditions, while the ESs between HASR and LASR were quite similar, which may be a limitation. Nevertheless, ASR profile categorization could play an important role for high-intensity running-based exercise prescription according to competition demands and, therefore, optimize sport-specific performances. In this regard, recent evidence supports the use of percentages of ASR for prescribing exercise intensities above MAS (i.e., short format HIIT), since this variable reduces interindividual variability in acute responses to exercise, and allows to consider the individual tolerance to high-intensity exercise of an athlete (Bok et al. 2023; Thron et al. 2024). In this regard, proper training parameters manipulation (e.g., different HIIT protocols, work-to-rest ratio, interval duration, and intensity) during short

Fig. 2. Correlation with 95% confidence interval bands between differences in countermovement jump height (CMJ) and maximal sprint speed (MSS) during the non-fatigued and fatigued conditions for the high anaerobic speed reserve (HASR, upper panel) and low anaerobic speed reserve (LASR, lower panel) groups.



format HIIT sessions may optimize acute responses and adaptations in the short and the long term (Varela-Sanz et al. 2023).

Another interesting result is the correlations found between ASR, CMJ, and MSS in both non-fatigued and fatigued conditions. Thus, it seems that, in our sample, those athletes with greater ASR also present a greater CMJ and a higher MSS. Interestingly, this relationship is more evident in the LASR group given the correlation observed between ΔCMJ and ΔMSS ($r = 0.84$, $p \leq 0.001$). This may confirm the practicality of CMJ for monitoring acute and chronic responses related to PAPE. More studies are needed to investigate the influence of ASR on PAPE responses during different endurance exercises, particularly when ASR-based HIIT prescription is considered (Buchheit and Laursen 2013; Coates et al. 2023), and to verify the influence of MAS on these responses, given that differences in ASR in the current study were mainly debt to differences in MSS between groups. This would be especially important in those sports requiring higher jumping and sprinting abilities (i.e., team sports). Furthermore, these performance parameters may change throughout the season depending on the athlete's physical fitness level, thus it could be hypothesized that PAPE response would also be modified. In this sense, future research is needed to verify if a minimum level of aerobic power and, hence a lower ASR, would counteract the negative effects of fatigue in those athletes with greater neuromuscular performance. Meanwhile, we did not evaluate the potential influence of sex on these responses because of the limited sample size of female runners, with females presenting both lower aerobic and anaerobic power capacities which directly affect the ASR calculations.

Based on our results, it seems that ASR can have a potential influence on PAPE responses in endurance athletes, with a low ASR more beneficial than a high ASR. Given that PAPE could be a key mechanism by which muscles can counteract the effects of fatigue during endurance events (Del Rosso et al. 2016) thus improving performance, it would be pertinent to monitor the impact of both ASR and PAPE responses on running performances in endurance athletes of different training background and aerobic statuses (e.g., long- vs. middle-distance runners). It can be also suggested that endurance athletes with a lower ASR would be more benefited for PAPE responses because of a better potentiation/fatigue balance after high-intensity endurance exercises. Therefore, a lower ASR may be appropriate to increase the neuromuscular performance via PAPE responses during high-intensity training sessions (Varela-Sanz et al. 2023). Finally, considering the correlation between ΔCMJ and ΔMSS, it would be also suggested the use of a simple lower limbs' power test as CMJ to assess the runners' potential to sprint under fatigued conditions. Of note, the non-significant differences regarding MSS before and after the UMTT may also suggest that MSS can be evaluated after the UMTT to save time for ASR calculation purposes.

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Data availability

The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to confidentiality and anonymity of the study participants.

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The authors declare there are no competing interests.

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