CrossTalk proposal: Heat acclimatization does improve performance in a cool condition

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Introduction

Repeated exposure to a hot climate (i.e. acclimatization) or artificial environment (acclimation), hereafter collectively termed HA, elicits greater cardiovascular and thermoregulatory adaptations than are obtained by training in temperate conditions (Convertino *et al.* 1980; Cohen & Gisolfi, 1982). Endurance performance is optimized in relatively cool temperatures (∼10–14°C; Ely *et al.* 2007*a*), and deteriorates with modest increases in temperature (Galloway & Maughan, 1997; Ely *et al.* 2007*b*). Regardless, heat strain is still present during strenuous exercise in cool conditions, evident by sweating and elevated skin blood flow, and HA may confer additional cross adaptations for exercise performance. In this CrossTalk article, we present evidence supporting the case that HA is ergogenic in certain individuals and exercise settings. However, we acknowledge there are currently more questions than answers on the ergogenic utility of HA – including many of the same questions that apply to hypoxic/altitude training despite the longer interest in that stressor as an ergogenic training aid.

HA can be ergogenic

Potentially ergogenic physiological adaptations, observed mostly from acute or short-term adaptive studies of heat stress, include haematological (expansion of plasma volume), vascular (function then structure), cardiac and skeletal muscle (metabolic efficiency, ventricular compliance, stress protection, hypertrophic/anti-atrophic), and thermoregulatory adaptations (lower resting core temperature, increased sweating and cutaneous blood flow, heat shock protein induction in multiple tissues) (Ruell *et al.* 2004; Corbett *et al.* 2014). Potential ergogenic outcomes include increased maximal cardiac output or reduced submaximal heart rate; improved fluid balance; increased aerobic power and efficiency; slower heat accumulation in tissues and organs; enhanced cellular protection; and increased metabolic capacity (Corbett *et al.* 2014; Periard *et al.* 2015). The extent to which such adaptations improve performance is poorly resolved, especially in elite athletes, and it is likely that there will be a high degree of individual variation. That said, there is evidence of an ergogenic or performance benefit of HA in some settings.

Early studies showed an increased $\dot{V}_{O_{2max}}$ across HA in relatively untrained participants (Shvartz *et al.* 1977; Takeno *et al.* 2001) or using uncontrolled experimental designs (i.e. lacking a control condition) (Shvartz *et al.* 1977; Sawka *et al.* 1985). In sub-elite endurance ($\dot{V}_{O_{2max}}$ ∼60 ml min^{-1} kg^{-1}) and team-sport athletes, improved performance and related physiological adaptations following HA have been shown in cool to temperate indoor environments (≤ 23°C). Scoon and colleagues used a crossover study design and showed an ∼29% increase in running time-to-exhaustion (which equates to 2% increase in velocity) over ∼5 km in runners after 3 weeks of sauna bathing immediately following each training session, *versus* controlled training (Scoon *et al.* 2007). The performance benefit correlated closely with plasma volume expansion. Importantly, HA was passive so the ergogenic effect could not be attributed to additional training. Lorenzo *et al.* studied sub-elite male and female cyclists over 10 daily 90-min bouts of cycling at matched absolute intensity in hot or temperate conditions, and showed 5–8% improvements in a lab-based 1 h time trial, anaerobic threshold, $\dot{V}_{O_{2max}}$ and cardiac output at 13°C (Lorenzo *et al.* 2010). In these two studies, HA was separated from outdoor training such that absolute training intensity and load were not compromised, and accumulated fatigue was minimized. In a more recent (uncontrolled) study employing short-term HA with permissive dehydration, Neal and colleagues reported evidence of an ergogenic benefit following HA in cyclists, with higher power output at lactate threshold and maximal graded exercise, and a trend ($P = 0.06$) for higher mean power output during a 20 km time trial (Neal *et al.* 2015). Importantly, these three studies utilized lab-based performance tests, which may underestimate the cooling effects of airflow compared to high-speed cycling outdoors (Saunders *et al.* 2005). Regardless, the studies displayed evidence of an ergogenic benefit.

Intermittent running tests in temperate environments were also improved following uncontrolled HA in team sports players during 7 and 14 day heat training camps, which correlated with the observed plasma volume expansion (Buchheit *et al.* 2011, 2013). Relative to elite endurance athletes,

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team-sport and sub-elite athletes have lower blood volume (Schmidt, 1988), and thus obtain an inotropic benefit from its expansion (Hopper *et al.* 1988; Luetkemeier & Thomas, 1994) that offsets any detrimental effect of haemodilution. Collectively, these studies demonstrate that HA provides an ergogenic benefit in sub-elite athletes, potentially due to their sub-optimised haematological, myocardial and vascular adaptations.

When might HA not be ergogenic?

HA may be less beneficial for prone or less heat-stressful exercise, such as swimming, but the available data are sparse and conflicting (Hue *et al.* 2007; Bradford *et al.* 2015). Along these lines, Karlsen *et al.* reported no improvement in peak aerobic power or outdoor time-trial performance in cool conditions in a group of sub-elite cyclists that travelled to a hot environment for a training camp (Karlsen *et al.* 2015). It is likely that an enhanced convective and evaporative cooling with outdoor cycling results in a lower required skin blood flow and less strain on venous return. It is important to note that the high-intensity interval training in this study was performed in the hot environment. While efforts were made to maintain workloads by performing them in the early part of the training, they were performed in the heat, resulting in more time spent above 80% of maximum heart rate (HR_{max}) in the HA group compared to the control group. Whether fatigue due to training in the heat or travel affected the performance was not determined. Similarly, Keiser *et al.* recently reported no increase in lab-based performance tests following HA (Keiser *et al.* 2015). In this study, athletes were passively pre-heated before performance tests in an effort to examine the impact of HA at standardized heat strain conditions. However, this may have obscured some of the benefits of HA on lowering core temperature and required skin blood flow during exercise. Although a cross-over design was employed in this study, statistical significance was not achieved with the sample size used despite apparent increases in performance variables observed after HA but not Control. Unfortunately, individual data were not presented in either of these studies, which is a key issue, since HA seems to be similar to altitude training in showing responders and non-responders (Levine and Stray-Gundersen, 1997; Racinais *et al.* 2012).

Many issues are unresolved or unexamined

Hypervolaemia appears to be a beneficial adaptation of HA. Because it develops rapidly (<1 week), very short HA regimes in periodization or tapering are attractive but barely examined (Sunderland *et al.* 2008). The longevity of hypervolaemia is unresolved, as is erythropoiesis in HA. Erythropoietic effects appear unlikely (Takeno *et al.* 2001; Scoon *et al.* 2007; Buchheit *et al.* 2013), although most HA regimes in athlete-performance studies are relatively brief (<15 h cumulative exposure), so this potential effect remains unknown. Animal studies from Horowitz's laboratory have shown that many important HA adaptations take longer to fully manifest than has been investigated in performance studies (Horowitz & Kodesh, 2010). Whether such findings apply to human endurance athletes remains unexamined, but seems particularly relevant.

Summary

We believe available data support the thesis that HA *can* improve performance in cool conditions, and perhaps with less expense and fewer side-effects than hypoxia (Dempsey & Morgan, 2015), but its utility is unresolved and may be modest or absent in some settings and individuals. A few key issues are becoming clear, however. First, HA must be of sufficient stimulus and duration, with key evidence indicating longer is better. Second, individual variability in response to HA as an ergogenic aid needs to be considered. Third, key training aspects such as speed and intensity may need to be maintained, and ideally performed in a cooler environment to maximize gains and minimize fatigue (including the effects of matched absolute *versus* relative work rates on adaptations). Alternatively, passive heating should be considered (e.g. immediately after training). Fourth, there is no evidence that HA impairs cool weather performance, and thus HA is a useful strategy when the competitive environmental conditions are potentially hot or unknown. Fifth, much remains unknown about ideal timing for competition following HA and its decay. Lastly, an ergogenic effect of HA has yet to be studied in truly elite athletes.

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Additional information

Competing interests

None declared.