CROSSTALK

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CrossTalk opposing view: Heat acclimatization does not improve exercise performance in a cool condition

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It is clear that heat acclimatization markedly improves endurance performance in hot environments (Sawka *et al.* 1985; Nielsen *et al.* 1993; Racinais *et al.* 2015), but the idea that physiological adaptations achieved via heat acclimatization will also transfer to improved performance in cooler environments is questionable. Except from studies suffering from the lack of a matched control group, only one recent study, by Lorenzo *et al.* (2010), provides evidence for a transfer effect, as the authors report remarkable improvements in maximal oxygen consumption and ergometer time trial performance in both hot and cool conditions following 10 days of heat acclimation training. In that study acclimation was achieved through 90 min of additional training per day conducted in climatic heat chambers combined with maintenance of the participants' habitual training (volume or intensity not reported or quantified). In contrast we observe no change in outdoor bicycle or laboratory ergometer time trial performance, peak power output during incremental indoor cycling, or maximal oxygen consumption when endurance trained cyclists are tested in cool conditions following either 10 days of indoor heat acclimation (Keiser *et al.* 2015), i.e. similar to the approach used by Lorenzo *et al.* (2010), or after 14 days of outdoor natural dry heat acclimatization (Karlsen *et al.* 2015). However, both regimes did facilitate improvements in time trial performance when conducted in the heat and were fully compatible with those reported to occur in the heat by Lorenzo *et al.* (2010). Furthermore, the sudomotor and cardiovascular adaptations were similar to the physiological heat acclimatization effects reported in studies of similar duration (Nielsen, 1998; Racinais *et al.* 2012; Taylor, 2014).

The premise for concluding that heat acclimatization improves aerobic performance in athletes exercising in cool conditions requires that there is a truly additional effect achieved from acclimatization that will translate into performance gains, and that the observations are not just a normal training effect or influence by the participation in a scientific study, which indeed may influence performance if the participating athletes do not have an optimized and stable training period prior to the intervention (Levine & Stray-Gundersen, 1997). Several studies with no control group report that completing a training camp in the heat may elevate the participants' physiological performance capacity (Hue *et al.* 2007; Buchheit *et al.* 2011; Racinais *et al.* 2014), but so may a period with improved training quality in cool conditions (Laursen *et al.* 2002; Iaia *et al.* 2008). Therefore, it is essential to secure that pre-tests represent the highest level that the subjects will achieve from optimized training in cool conditions and, if applicable, the scientific gold-standard design of blinded, placebo-controlled, cross-over trials should be utilized (Lundby *et al.* 2012; Siebenmann *et al.* 2012). For obvious reasons blinding is not possible in heat acclimatization studies and it may also be discussed how training should be matched across conditions as heat stress will elevate the relative intensity if similar work load is utilized, whereas a higher work load may be endured in cool conditions if heart rate is used to match the exercise intensity across conditions. However, both when matched for heart rate during indoor control *vs.* heat acclimation training (Keiser *et al.* 2015) or allowing heat stress to influence the relative exercise intensity during natural outdoor training (Karlsen *et al.* 2015), we observe that heat acclimatization does not transfer to improved performance in cool or moderate temperature conditions for competitive cyclists who have been training for several years with inclusion of high intensity intervals in their habitual training.

Our opponents propose that the mechanism for heat training to improve exercise performance in a cool environment is linked to concomitant increase in plasma volume (Lorenzo *et al.* 2010), although this is not supported by experimental evidence. However, this is controversial as Kanstrup & Ekblom (1982), for example, reported no effect of acute plasma volume expansion on $\dot{V}_{O_2\max}$ in well-trained endurance athletes and in our recent studies neither acute plasma volume (PV) expansion nor the increase in PV associated with heat acclimation or acclimatization training facilitated time trial performance or improved the participants' maximal aerobic power (Karlsen *et al.* 2015; Keiser *et al.* 2015; see also Fig. 1). In contrast, acute PV expansion may have a moderate effect on $\dot{V}_{O_2\max}$ in untrained men (Coyle *et al.* 1990) and the differences across observations may relate to training status of the subjects and their habitual training. Thus heat acclimation has been reported to increase $\dot{V}_{O_2\max}$ in untrained subjects

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(Nadel *et al.* 1974; Shvartz *et al.* 1977; Sawka *et al.* 1985), whereas in trained subjects only Lorenzo *et al.* (2010) report an improvement, while we (Karlsen *et al.* 2015; Keiser *et al.* 2015) and others (Shvartz *et al.* 1977; Kirby & Convertino, 1986; Houmard *et al.* 1990; Gore *et al.* 1997; Chen *et al.* 2013) observe no change in $\dot{V}_{O_2max}$ after heat acclimation or outdoor training in the heat. It should be emphasized however that only a few of the cited studies included a control group (Lorenzo *et al.* 2010; Karlsen *et al.* 2015; Keiser *et al.* 2015) while the remaining studies were designed with other aims as the primary purpose and were not focused on comparing performance effects across environmental conditions. Another factor that may influence the opposing observations across studies could relate to the magnitude of the PV expansion evoked by acclimatization. As proposed by Coyle *et al.* (1990), untrained humans may benefit from a moderate PV expansion, while the induced haemodilution and lower oxygen carrying capacity associated with an acute large PV expansion will outweigh the effects of the augmented stroke volume and cardiac output. For endurance trained subjects with high plasma volumes, it is therefore expected and verified with our recent study (Keiser *et al.* 2015) that further haemodilution will not benefit arterial oxygen delivery.

Improved exercise efficiency is another proposed physiological adaptation from heat acclimation that potentially could benefit exercise performance in cool conditions (Sawka *et al.* 1983). However, exercise economy is indeed a factor that may be affected by familiarization with the experimental set-up, and results from studies that include training on the same equipment used for testing should be interpreted with great caution. For a trained group of cyclists, we observed no change in delta or gross cycling efficiency following heat acclimatization (Karlsen *et al.* 2015).

Hence, for endurance trained subjects the energy cost of exercise appears to be robust to heat acclimatization and since plasma volume expansion fails to elevate maximal oxygen uptake in this group of subjects, we conclude that there is no additional effects of training in the heat in terms of improving exercise performance in cool environments. In this context we emphasize that cool condition refer to the range of environmental conditions where performance is not influenced by hyperthermia (Nybo *et al.* 2014) and in this perspective the exercise mode needs to be considered as that will affect the combined exercise and environmental heat stress (Nybo, 2010; Corbett *et al.* 2014). We also emphasize that training in the heat does not preclude that subjects may benefit from training or that well-trained subjects can maintain their performance capacity in cool conditions concomitantly with adapting to exercise in the heat. However, there is no evidence supporting superior effects of training in the heat as compared to training in cool climates in terms of improving exercise performance in a cool environment.

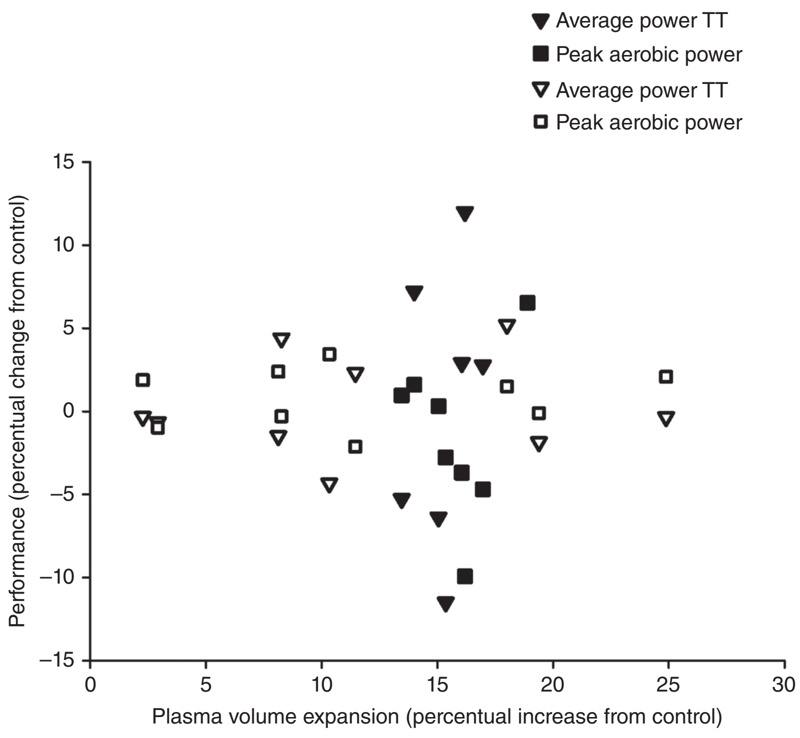

Figure 1. Changes in physiological performance capacity *versus* change in plasma volume
Changes in physiological performance capacity evaluated in cool conditions (triangles representing average power output during time trials (TT) and squares representing peak aerobic power during incremental exercise testing) *versus* the percentage change in plasma volume following acute plasma volume expansion (filled symbols; albumin infusion) or 2 weeks of natural outdoor heat acclimatization (open symbols). The symbols represent individual values from Karlsen *et al.* (2015) and Keiser *et al.* (2015) with the delta changes calculated as the percentage increase from control.

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Additional information

Competing interests

None declared.