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Hydration status, executive function and response to orthostatism following a 118-km mountain race: ¿are they interrelated?

Running head: Hydration status, executive function and response to orthostatism after an ultramarathon

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Abstract

Purpose. The present study aimed to explore whether Blood Pressure (BP) and Heart Rate Variability (HRV) responsiveness to orthostatism, jointly with Executive Function (EF) performance, were diminished following an ultraendurance mountain race. Besides, we wanted to assess whether hydration status was related to either performance or the abovementioned alterations.

Methods. Fifty recreational ultraendurance athletes participating in the Penyagolosa Trails CSP115 race (118 km and a total positive elevation of 5439 m) were evaluated before and after the competition. HRV and BP were measured in response to an orthostatic challenge. EF was evaluated using the color-word interference task of the Stroop test. Body Mass (BM) and Urine Specific Gravity (USG) changes were employed to assess hydration status.

Results. HRV and BP responsiveness to orthostatism were diminished following the race. Besides, a significant BM loss of 3.51 ± 2.03% was recorded. Conversely, EF and USG showed no significant changes from prerace to postrace. Eventually, BM loss was inversely related to finishing time (r=-0.34) and postrace orthostatic HR and EF were positively associated (r=0.60).

Conclusions. USG and BM loss appears to provide different insights into hydration status and our results challenge the well-established criteria that BM losses >2% are detrimental to performance.

Practical Applications. Coaches are advised to consider athletes' performance level when interpreting their BM changes during an ultraendurance competition. Similarly, coaches should be aware that increased vulnerability to orthostatism is a common phenomenon following ultraendurance races and diminished HR responsiveness to orthostatism could constitute a practical indicator of EF worsening.

Keywords: Ultraendurance; Heart Rate Variability; Stroop test; Urine Specific Gravity; Performance

1. INTRODUCTION

The acute effects of ultraendurance races are the main point of an increasing number of research studies, encompassing fields such as cardiac haemodynamics, inflammation, muscle damage, sleep management, cognitive performance, central and peripheral fatigue or hydration status. Indeed, this latter and its influence on performance during endurance exercise has been the object of an intense debate in the literature (17, 32, 40) and it remains a matter of concern for ultraendurance coaches. Similarly, management of increased vulnerability to orthostatic challenges and cognitive performance worsening during ultraendurance races are relevant to ultraendurance coaches' practice (10, 18, 22, 29, 30, 33). However, previous literature does not offer studies providing a joint assessment of those three fields (i.e., hydration status, orthostatic tolerance and cognitive performance) following an ultraendurance event. Such approach would enable to examine whether ultrarunners who display greater end-of-exercise Body Mass (BM) losses are proner to increased vulnerability to orthostatic challenges or cognitive performance worsening; or whether responsiveness to orthostatism and cognitive performance are interrelated.

Exercise-induced dehydration has been demonstrated to alter baroreflex sensitivity and contribute to orthostatic intolerance under a laboratory setting (i.e., 90 min cycling at 55% VO2peak wearing water-impermeable plastic garments) (7). However, as far as we are aware, only one study has previously assessed Heart Rate Variability (HRV) and Blood Pressure (BP) responsiveness to orthostatism, jointly with hydration status, following a competitive ultraendurance event (i.e., mountain marathon) (33). Although they did not attempt to find possible associations between HRV and BP responses to orthostatism and postrace hydration

status, the authors concluded that differences in hydration status were not responsible for the reduction in orthostatic tolerance, inasmuch as Urine Specific Gravity (USG) did not change from prerace to postrace. In a similar manner, only Mahon and cols. (30) have previously assessed a possible relationship between cognitive performance impairment and dehydration following an ultraendurance event. Contrary to the authors' expectations, they failed to find significant differences in a choice reaction time test as a function of hydration status (i.e., USG).

Therefore, our first purpose was to examine the effect of an ultraendurance event upon Executive Function (EF), which it is assimilated as the orchestra director regarding cognitive processing (14), on one hand; and BP and HRV response to orthostatism, on the other hand. We were also interested in assessing whether EF, orthostatic tolerance and hydration status following an ultraendurance event may keep any relationship. Eventually, our aim was also to broaden previous findings in relation to the role played by dehydration regarding the achievement of best performance. Our study hypothesis was that athletes would show diminished BP and HRV responsiveness to orthostatism and their EF would be impaired following the race. We also hypothesized that orthostatic intolerance and executive function worsening would be interrelated. Eventually, our third hypothesis was that faster runners would display a greater end-of-exercise BM loss.

2. METHODS

2.1. Experimental approach to the problem

This research was carried out at the Penyagolosa Trails CSP115 race in 2015 (May 9th - 10th). The track consisted of 118 km, starting at an altitude of 40 m and finishing at 1280 m above the sea level, with a total positive and negative elevation of 5439 and 4227 m respectively. Temperature and humidity were recorded at the start, at 2 midpoints during the race (72.3 km and 91.1 km) and at the finish line. EF jointly with HRV and BP responsiveness to orthostatism were assessed in the afternoon the day before the race and within 30 min following race completion. Hydration status was estimated in duplicate from USG and from changes in BM. USG was measured from a first-morning-void urine sample (the day of the race) and the first-postrace-void urine sample. BM was measured within 1 h before race start and immediately after crossing the finishing line. Participants were informed to avoid caffeine and exercise in the 12 h before prerace testing. Participants were also informed not to consume any large meal in the previous 4 h. During postrace evaluation participants were allowed to drink but not eat. Finishing time was considered as an independent variable.

2.2. Subjects

Fifty recreational ultraendurance athletes (44 men and 6 women) were recruited to participate in the study. Selected athletes were required to have previously completed at least one ultramarathon (>60 km). A questionnaire was used to collect demographic information as well as training and competition history. All athletes considered the Penyagolosa Trails CSP115 as their main competitive goal of the season. The characteristics of the sample are presented in **Table 1**. All subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document. They were also allowed to

withdraw from the study at will. The investigation was conducted according to the Declaration of Helsinki, and it was approved by the Research Ethics Committee of the University Jaume I of Castellon.

**** Insert Table 1 near here ****

2.3. Procedures

Orthostatic challenge consisted of 8 min of supine bed rest followed by 7 min in an upright free-standing posture (43, 44). To limit the effect of the skeletal muscle pump, subjects were instructed not to make any major muscle contractions at supine and standing postures. Beat-to-beat HR was recorded continuously using a Polar RS800 HR monitor together with a Polar Wearlink Wind electrode transmitter (Polar Electro, Kempele, Finland), after application of conductive gel as recommended by the manufacturer. This instrument has been previously validated for the accurate measurement of RR intervals in young and middle-aged men (12, 53). Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP) were measured after 2 min of supine bed rest and after assuming the upright free-standing posture, using an automatic digital BP monitor (Model M6-IT, OMRON, Kyoto, Japan) with the cuff at heart level. Orthostatic Hypotension (OH) was defined as a drop of ≥20 mmHg SBP or ≥10 mmHg DBP on standing (42). Respiratory rate was not controlled to not interfere in athletes' recovery, although they were asked to avoid irregular respiration. Normal respiratory rate does not result in significantly different heart rate-derived indices compared with controlled breathing (4).

RR intervals were transferred to Polar Pro Trainer 5 software (Polar Electro, Kempele, Finland) and afterwards analyzed using Kubios HRV Analysis Software 2.0 (The Biomedical Signal and Medical Imaging Analysis Group, University of Kuopio, Finland). The whole analysis process was carried out by the same researcher to ensure consistency. Artifacts were identified and

corrected according to manufacturer's recommendations (47), and only those recordings with <1% of artifacts were considered. Accordingly with previous studies in the field (43, 44), analyses were performed on RR intervals recorded between the 3rd and 8th min supine, and between the 9th and 14th min standing. The following indices were obtained: mean heart rate (HR); the standard deviation of normal RR intervals (SDNN) as a measure of overall variability and the root-mean-square difference of successive normal RR intervals (RMSSD) as a measure of vagal modulation (48); the short-term scaling exponent (4 to 11 beats, $\alpha 1$) from Detrended Fluctuation Analysis to estimate sympathovagal balance and fractal correlation properties (52); and Sample Entropy (SampEn) to provide an indication of the complexity of the time-series under these circumstances (35). Time domain indices were chosen instead of spectral indices because of its greater intraindividual reproducibility (1).

Executive function was measured using the color-word interference task of the Stroop test, which it is considered a test of response inhibition (i.e., measures the ability to suppress an over-learned response) (16). The task consists of 100 stimuli (5 columns by 20 rows) printed on a 29.7 x 21 cm sheet of paper and the participant has to name the color of the ink in which the words are written, ignoring the automatic reading of the word's incongruent meaning (i.e., the word "blue" written in red ink). The number of correct items named within 45 s was employed to measure the performance (15).

BM measurements were made with calibrated electronic scales (Seca 813, Vogel and Halke; Hamburg, Germany) that were on firm surfaces. Prior to the event, the scales were examined for consistency. Following a previous study (20), both prerace and postrace measurements were made with the runner clothed in running wear and shoes, but other items such as waist packs and hydration vests were removed and nothing was permitted in the runner's hands. Based on USG, participants were categorized as adequately hydrated (<1.020 g/ml), as mildly dehydrated (1.020 to 1.030 g/ml) or as severely dehydrated (>1.030 g/ml) (5, 25). Considering BM change,

a loss >4% was classified as dehydration, a loss ≤1% as overhydration and a loss between 1 and 4% as euhydration (20, 34).

2.4. Statistical analysis

Statistical analyses were carried out using the Statistical Package for the Social Sciences software (IBM SPSS Statistics for Windows, version 22.0, IBM Corp., Armonk, NY). After testing for normal distribution (Kolmogorov-Smirnov test, with Lilliefor's correction), SDNN and RMSDD were logarithmically transformed to allow parametric comparisons.

A repeated measures multivariate ANOVA was used to assess the effects of race and posture (supine versus standing) and their interaction on BP and HR dynamics indices. For each ANOVA, if a significant main effect or interaction was identified, pairwise comparisons were adjusted using Bonferroni's correction. Additionally, relative changes from supine to standing position (orthostatic changes) in BP and HR dynamics indices were compared between prerace and postrace using a paired samples Student's t-tests. USG, BM and Stroop performance were compared before and after the race using paired samples Student's t-tests.

Pearson correlation and partial correlation analyses were conducted among selected variables. Firstly, we analyzed whether performance was associated with BM, USG and Stroop performance. Secondly, we assessed possible relationships among Stroop performance, hydration status (i.e., BM change and postrace USG) and postrace orthostatic change in HR dynamics indices, SBP and DBP. Stroop performance analyses were adjusted by age. The meaningfulness of the outcomes was estimated through the effect size (ES, means divided by the standard deviation): an ES<0.5 was considered small; between 0.5-0.8, moderate; and greater than 0.8, large (50). Likewise, correlations greater than 0.5 were considered large;

between 0.3 and 0.5, moderate; and smaller than 0.3, small (50). The significance level was set at p-value<0.05 and data are presented as means and standard deviations (±SD).

3. RESULTS

Thirty three athletes (29 men and 4 female) successfully completed the race (finishers/starters ratio: 68%) with an average finish time of 22 h 29 min ± 3 h 43 min. Both the average finish time and the finishers/starters ratio for the subjects of the present study were similar when all race participants were considered (22 h 37 min ± 3 h 47 min and 63.5%, respectively). Furthermore, all levels of performance were represented in our sample as shown by their rank ranging from 3rd to 286th place (of 291 finishers). Temperature at the start was 23.2°C and it ranged between 21.7 and 23.8°C (1st midpoint), 13.5 and 19.4°C (2nd midpoint), and 9.9 and 15°C (finish line). Humidity at the start was 48% and it ranged between 41 and 47% (1st midpoint), 50 and 67% (2nd midpoint), and 55 and 68% (finish line).

Orthostatic challenge

Nine participants resigned to undergo either prerace or postrace orthostatic test due to time constraints. Three participants were excluded from HR dynamics analyses due to an excessive number of artifacts (>1%) in their HR recording. Postrace, six participants could not assume the standing position because of sickness and/or dizziness and four participants showed OH. Prerace, all of the subjects completed the orthostatic challenge and none of them exhibited OH. Sixteen participants were eventually included in HR dynamics analysis and nineteen in BP analysis.

Univariate contrast analysis revealed a significant effect for 'race' on HR [$F = 12.75$; $p<0.01$; $\eta 2$ partial = 0.46], lnSDNN [$F = 9.72$; $p<0.01$; $\eta 2$ partial = 0.39], lnRMSSD [$F = 8.19$; $p<0.05$; $\eta 2$

partial = 0.35] and SampEn [F = 8.39; p<0.05; η2 partial = 0.36]. 'Posture' factor significantly affected HR [F = 75.39; p<0.01; η2 partial = 0.83], lnRMSSD [F = 11.86; p<0.01; η2 partial = 0.44], α1 [F = 55.28; p<0.01; η2 partial = 0.79] and SampEn [F = 52.11; p<0.05; η2 partial = 0.78]. However, no significant effects were found for 'race x posture' interaction. Pairwise comparisons showed that HR was significantly lower in prerace compared to postrace recording (p<0.01); whereas lnSDNN, lnRMSSD and SampEn were significantly higher in prerace recording (p<0.05). Meanwhile, HR and α1 were significantly lower in supine posture compared to standing, while lnSDNN and SaEn were significantly higher in supine posture (p<0.01 in all cases). In addition, orthostatic change in HR and RMSSD were significantly and largely attenuated following the race (15.05 ± 12.09% vs. 21.78 ± 9.89%, ES=-0.63, p<0.05; -4.24 ± 52.96% vs. -31.87 ± 12.12%, ES=0.72, p<0.05 respectively). **Figure 1** and **Table 2** show the time course of HR dynamics indices during orthostatic challenge before and after the race.

***** Insert Figure 1 and Table 2 near here *****

Regarding BP analysis, univariate contrast analysis showed a significant effect for 'race' on SBP [F = 23.03; p<0.01; η2 partial = 0.56] and a significant effect for 'posture' on DBP [F = 51.52; p<0.01; η2 partial = 0.74]. In addition, 'race x posture' interaction significantly affected both SBP [F = 10.50; p<0.01; η2 partial = 0.37] and DBP [F = 6.94; p<0.05; η2 partial = 0.28]. Further pairwise comparisons revealed that in prerace condition SBP and DBP significantly and largely increased from supine to standing (125.10 ± 11.10 vs 131.58 ± 13.82 mmHg, ES=0.53, p<0.01; 74.79 ± 7.07 vs 85.16 ± 7.82 mmHg, ES=1.43, p<0.01 respectively), whereas following the race no significant changes were observable (118.84 ± 13.75 vs 113.58 ± 12.53 mmHg and 75.26 ± 8.42 vs 78.42 ± 9.62 mmHg). Additionally, orthostatic change in both SBP and DBP were significantly and largely diminished following the race (-3.84 ± 10.17% vs. 5.18 ± 5.91%, ES=-1.11, p<0.01; 4.71 ± 11.18% vs. 14.08 ± 6.53%, ES=-1.05, p<0.05 respectively). **Figure 2** shows the time course of SBP and DBP during orthostatic challenge before and after the race.

***** Insert Figure 2 near here *****

Executive function

Stroop performance did not change from prerace to postrace condition (47.32 ± 8.27 vs. 46.29 ± 7.52 correct items; p=0.30). Correlation analyses showed that both prerace (using a partial correlation controlling for age differences) and ΔStroop performance were unrelated to finishing time.

Hydration status

All of the finishers were assessed on BM but unfortunately only 23 postrace urine samples could be collected. BM showed a significant but small decrease following the race (68.12 ± 8.77 vs 70.63 ± 9.20 kg, ES=-0.28, $p<0.01$), with a mean percentage BM loss of 3.51 ± 2.03%. On the contrary, USG showed no significant changes from prerace to postrace (1.020 ± 0.005 vs 1.021 ± 0.005 g/ml; p=0.36). Thirteen participants (38.2%) were identified as dehydrated and 3 participants (8.8%) as overhydrated according to their BM change. Meanwhile, considering USG values, mildly dehydration was identified in 9 athletes (26.5%) before the race and 11 athletes following the race (47.8%), whereas no significant dehydration was found either prerace or postrace. ΔBM and postrace USG displayed a nearly significant correlation (r=0.39; p=0.06). However, relative change in BM from prerace to postrace was inversely and moderately associated with finishing time (r=-0.34; $p<0.05$), whereas no significant relationship was identified between finishing time and postrace USG. Eventually, prerace BM and USG were also unrelated to finishing time.

Relationship between orthostatic challenge, executive function and hydration status

ΔStroop was unrelated to postrace USG and ΔBM, but it was largely correlated with postrace orthostatic change in HR (r=0.60, p<0.01; **Figure 3**). No relationship was found between either postrace USG or ΔBM and postrace SBP, DBP and HR dynamics orthostatic change.

***** Insert Figure 3 near here *****

4. DISCUSSION

In this study we analyzed 50 participants of a 118-km mountain race providing a joint assessment of BP and HRV responsiveness to orthostatism, EF and hydration status before and after the race. According to our results, BP and HRV responsiveness to orthostatism are altered following an ultra-distance mountain competition. However, contrary to our hypothesis, EF did not declined after the race. Regarding hydration status, USG did not change from prerace to postrace while a significant BM loss of 3.51 ± 2.03% was recorded. Moreover, BM loss was inversely correlated with finishing time whereas no relationship was found between USG and performance. Eventually, orthostatic HR response following the race showed a large relationship with executive performance.

Hydration status

The significant decrease in BM following the race is in line with several previous studies (19-21, 24, 30, 38, 41, 45, 46, 56). Likewise, our mean percentage BM loss (3.51%) falls within formerly reported following other ultraendurance competitions: greater than that measured after shorter races (i.e., 80.5-km mountain race, 85-km mountain race or 100-km flat race) (30, 38, 41), but smaller than that recorded following longer or multi-stage races (i.e., Ironman triathlon,

24-h ultramarathon or Marathon of Sands) (24, 45, 56). According to BM loss, our percentage of dehydrated athletes (38.2%) is also within the range reported by Hoffman and cols. (19) after analyzing 887 athletes at northern California 161-km ultramarathons during 5 consecutive years (7.3 to 48.9%), whereas our percentage of overhydrated runners (8.8%) is close to the lower limit of this range (6.7 to 47.5%).

Concerning USG, prerace values indicated that 26.5% of runners were not adequately hydrated before the start. This outcome could be surprising at first sight; but considering that prerace USG was determined from morning first void, it is possible that athletes improved their hydration status in the time lapse before the start, as previously suggested (13). Regarding postrace values, previous studies carried out in other ultraendurance events have shown divergent results. Our absence of a significant prerace to postrace difference has been formerly reported after a mountain marathon, a 24-h ultramarathon or a 1230-km cycling event (9, 13, 33), whereas a significant increase has been observed following a 80.5-km mountain race, a 100-km flat race, a 24-h mountain bike race or an Ironman triathlon (9, 27, 30, 31, 38). According to USG values, our percentage of postrace mildly dehydrated participants (47.8%) is similar to that reported by Geesman and cols. (13) following a 1230-km cycling event (50%); while our absence of severely dehydrated athletes following the race also coincides with the abovementioned study but differs from Mahon and cols. (30), where an incidence of 22% was described following a 80.5-km mountain race.

Therefore, current outcomes further corroborate that USG and BM loss provide different insights into hydration status following an ultraendurance exercise. Actually, Rogers and cols. (37) postulated almost 20 years ago that approximately 60% of BM loss following a long-distance triathlon was due to factors other than pure fluid loss. And more recently, Mueller and cols. (31) have demonstrated using dual-energy X-ray absorptiometry measurements that BM loss following an Ironman triathlon was due to a 28 and 72% loss in fat and lean mass

respectively; being the latter attributable to a loss of glycogen, as fuel for energy production, and the corresponding loss of body water.

Regarding the association between performance and hydration status, the absence of a significant relationship between postrace USG and finishing time is consistent with a previous investigation (30). At the same time, the inverse relationship between BM change and finishing time reinforces previous studies conducted in endurance and ultraendurance events such as road marathons (55), 100-km flat ultramarathons (38), 161-km mountain ultramarathons (19), Ironman triathlons (46, 54), 24-h ultramarathons (24), and even a multi-stage trail race in tropical conditions (21). This plethora of results, however, takes issue with current guidelines advising that BM loss >2% should be avoided during endurance exercise (36, 39). Those guidelines, which state that such weight losses involve a level of dehydration that impairs aerobic exercise performance, are based upon laboratory-based studies employing shorter and fixed-intensity exercise protocols (17, 32). Therefore, considering the abovementioned results from Mueller and cols. (31) and the fact that none of our participants showed a severe dehydration according to USG results, it is arguable that greater weight losses among best performers during self-paced ultraendurance events could be mainly a reflection of their greater energy expenditure.

Orthostatic challenge

The incidence of sickness/dizziness (6 out of 31) in assuming the upright posture following the race was smaller than previously reported following either a mountain marathon (6 out of 7; 33) or an Ironman triathlon (7 out of 23; 18). Our results showed that cardiac autonomic modulation during supine rest became less complex and more predictable following the race (i.e., lower SampEn and higher α1); although the increase in α1 did not reach the significance level ($p=0.11$). Concomitantly, both overall and vagally mediated HRV (i.e., lnSDNN and lnRMSSD)

were significantly reduced in postrace assessment (see Table 2). This is in agreement with previous studies involving mountain marathon races (3, 33) and ultraendurance events (i.e., Ironman triathlon, 120 and 190-km mountain races; 11, 18).

However, orthostatic response varied across linear and nonlinear indices, and also between prerace and postrace evaluations (see Figure 2). Before the race, upright posture induced a significant decrease in lnRMSSD and SampEn jointly with a significant increase in α1. This could be considered the likely HR dynamics response to an orthostatic challenge (51). After the race, SampEn and α1 kept a similar response to the orthostatic challenge while lnRMSSD did not change from supine to standing position. This blunted vagal reactivity has been previously reported following an Ironman triathlon (18); conversely, former studies conducted on mountain marathon races have shown a maintained vagal reactivity to orthostatic challenge (3, 33). Therefore, it seems that vagal responsiveness is greatly affected following an ultraendurance event (i.e., Penyagolosa Trails CSP115 and Ironman triathlon) compared to shorter races. Meanwhile, complexity and fractal properties of HR dynamics appears to be more resilient to exercise stress than linear HRV.

Despite increased sympathetic and reduced vagal modulation (i.e., augmented HR and α1 coupled with reduced lnSDNN and lnRMSSD), SBP during supine rest was reduced following the race, in line with previous studies (3, 18, 33). Furthermore, after the race blood pressure did not increase as a result of orthostatic challenge, whereas before the race SBP and DBP significantly increased from supine to standing position (see Figure 1). Gratze and cols. (18) also found that participants were unable to raise their SBP as a response to active standing following an Ironman triathlon, whereas Murrell and cols. (33) even reported a significant decrease in orthostatic SBP and DBP after a mountain marathon race. Notwithstanding, in this latter study participants failed to show a significant increase in either SBP or DBP during baseline orthostatic test, unlike Gratze and cols. study (18) and ours.

Eventually, the absence of significant correlations between postrace BP and HR dynamics orthostatic response, on one hand, and hydration status (either measured by USG or BM change), on the other hand, corroborates that diminished orthostatic tolerance following a long-distance mountain race is unrelated to hydration status (33). Interestingly, whereas a previous laboratory study found that orthostatic HR significantly increased in response to an induced dehydration (8), our results show that postrace orthostatic HR was uncorrelated to BM change. Exercise-related effects on autonomic control of HR (i.e., reduced orthostatic responsiveness) might explain this contradictory results.

Executive function

The absence of a significant difference between prerace and postrace executive performance coincides with a former study carried out in a 100-h adventure race (28). However, other cognitive abilities such as psychomotor vigilance and choice reaction time have been shown to be diminished following ultraendurance events (i.e., 166-km Ultra Trail du Mont Blanc, a 36-h ultraendurance event, 80.5-km mountain race) (10, 22, 30). Therefore, it may be arguable that EF shows a greater resiliency than psychomotor vigilance and choice reaction time performance following an ultraendurance event, as previously suggested (49). Further studies including a broader cognitive assessment are nevertheless required to verify this postulate.

Meanwhile, the lack of a significant relationship between hydration status (either measured with USG or BM change) and Stroop performance following ultraendurance events endorse previous research in the field (30). The reasons why we observed no negative effects of dehydration on cognitive function is probably the absence of significant changes in Stroop performance following the race, on one hand; and the fact that dehydration was not severe enough among our participants to affect EF, on the other hand. Notwithstanding, Kempton and cols. (26)

demonstrated that acute dehydration provoked an increased neural activation during an EF task (i.e. compared to euhydration condition). Accordingly, they concluded that dehydrated participants exerted a higher level of neuronal activity to achieve the same performance level. Therefore, we could not discard that exercise-related dehydration in our study could have also led to this detrimental effect.

Besides, Cona and cols. (6) have recently observed a significantly baseline better cognitive functioning (i.e., inhibitory control and dual tasking) in faster vs. slower runners of an ultradistance mountain race (i.e., 80-km Trans d'Havet race). Our results, on the contrary, did not show a significant relationship between prerace Stroop performance and finishing time. Δ Stroop performance was also unrelated to finishing time, as previously observed for psychomotor vigilance performance (22). Conversely, the large relationship found between Δ Stroop performance and postrace orthostatic HR imply that athletes who showed lesser HR responsiveness displayed greater EF worsening (see Figure 3). Actually, Temesi and cols. (49) concluded that sympathetic nervous activation could buffer the drop in EF provoked by sleep deprivation and central fatigue following an ultraendurance event. Moreover, a controlled laboratory study showed that decreased performance in the Stroop test and lower cardiac autonomic reactivity were connected, and also constituted descriptive features of overtrained athletes (23).

Limitations

Similar to other related studies (3, 18, 33), we decided to employ the stand test because its practical and physiological generalizability to the realistic problems that occur following exhaustive and prolonged exercise (i.e., the difficulty to maintain an upright posture following a supine rest period). Although it is unclear how the hemodynamic changes during postural change may translate to those induced during a more severe orthostatic stress test (i.e., lower

body negative pressure, tilt), both active standing and passive head-up tilt have been reported to provoke comparable changes in spontaneous baroreflex and related hemodynamic variables (2).

5. PRACTICAL APPLICATIONS

Our results endorse previous field studies that challenge the well-established belief that euhydration is necessary to obtain the best performance during ultraendurance races. Therefore, it is advisory for coaches to take into consideration athletes' performance level when interpreting their BM changes during an ultraendurance competition. Contradictory results obtained from USG and BM measures lead us to suggest that greater weight losses among best performers during self-paced ultraendurance events could be mainly a reflection of their greater energy expenditure. On the other hand, coaches should be aware that increased vulnerability to orthostatism is a common phenomenon following an ultraendurance event, so sudden posture changes (i.e., from sitting to standing in an aid station) are advised against in the final stages of such a race. Eventually, diminished HR responsiveness to orthostatism could constitute a practical and important (in terms of safety) indicator of executive performance worsening during and at the end of ultraendurance events.

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Abbreviations: HR, Heart Rate; lnSDNN, Log-transformed standard deviation of normal RR intervals lnRMSSD, Log-transformed root-mean-square difference of successive normal RR intervals; α1, Short-term fractal scaling exponent; SampEn, Sample entropy. * Significantly different from prerace ($p<0.05$) ** Significantly different from prerace ($p<0.01$) $^{\#}$ Significantly different from supine position ($p<0.05$) $^{\#\#}$ Significantly different from supine position ($p<0.01$).

Figure 1. Relative change (%) of HR dynamics indices from supine rest to active standing before (black bars) and after the race (grey bars).

Abbreviations: HR, Heart Rate; SDNN, Standard deviation of normal RR intervals; RMSSD, Root-mean-square difference of successive normal RR intervals; α_1, Short-term fractal scaling exponent; SampEn, Sample entropy. * Significantly different from prerace ($p<0.05$) ** Significantly different from prerace ($p<0.01$).

Figure 2. SBP and DBP during supine (black bars) and standing (grey bars) positions prerace and postrace.

* Significantly different from prerace ($p<0.05$) ** Significantly different from prerace ($p<0.01$) # Significantly different from supine position ($p<0.05$) ## Significantly different from supine position ($p<0.01$).

Figure 3. Relationship between ΔStroop and postrace orthostatic change in HR.

Table 1. Sample main characteristics (mean ± SD)

	***n* = 50**
Age (years)	40.12 ± 7.01
Body mass (kg)	71.53 ± 9.25
Height (cm)	170.9 ± 6.1
BMI (kg/m^2)	24.43 ± 2.36
Years since 1st Ultramarathon (>60-km)	3.27 ± 2.91
Ultramarathons (>100-km) **races before event**	**%**
0	22.4
1	20.4
2	10.2
3	16.3
4	6.1
5	4.1
> 5	20.4
Average weekly sessions	4.61 ± 1.10
Average weekly training volume (hours)	**%**
< 12	42.9
12 - 15	34.7
16 - 20	16.3
> 20	6.1
Average weekly training volume (km)	65.81 ± 27.16

Abbreviations: BMI, BM Index.

Table 2. Linear and nonlinear HR dynamics during supine and standing positions before and after the race

	Prerace		Postrace		Significant main or interaction effects
	Supine	***Standing***	***Supine***	***Standing***	
HR (bpm)	63.73 ± 7.39	77.29 ± 8.57 ##	74.07 ± 9.35 **	84.60 ± 8.84 ##, *	race, posture
lnSDNN (ms)	3.53 ± 0.50	3.65 ± 0.39	2.98 ± 0.54 **	3.14 ± 0.57 **	race
lnRMSSD (ms)	3.49 ± 0.49	3.07 ± 0.40 ##	2.73 ± 0.81 **	2.54 ± 0.62 *	race, posture
α_1	1.11 ± 0.24	1.60 ± 0.18 ##	1.31 ± 0.40	1.63 ± 0.20 ##	posture
SampEn	1.74 ± 0.23	1.14 ± 0.27 ##	1.56 ± 0.24 *	1.02 ± 0.26 ##, *	race, posture

Abbreviations: HR, Heart Rate; lnSDNN, Log-transformed standard deviation of normal RR intervals lnRMSSD, Log-transformed root-mean-square difference of successive normal RR intervals; α1, Short-term fractal scaling exponent; SampEn, Sample entropy. * Significantly different from prerace ($p<0.05$) ** Significantly different from prerace ($p<0.01$) # Significantly different from supine position ($p<0.05$) ## Significantly different from supine position ($p<0.01$).