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Autonomic responses to training load and positive adaptation during an altitude-training camp of an elite triathlete: A case study

González-Fimbres Roberto A.[1], Hernández-Cruz German[2], Gutiérrez-García Pablo[1], Ramírez-Siqueiros María G.[1], Valencia-Falcón Teresita[1].
[1]*Licenciatura en Entrenamiento Deportivo, Universidad Estatal de Sonora.* [2]*Facultad de Organización Deportiva, Universidad Autónoma de Nuevo León.*

Abstract
The aim of this case study was to report the $LnRMSSD_M$ and $LnRMSSD_{CV}$ responses to ITL, ETL and performance from four 3-week training periods at altitudes of: 1) 200m PRE, 2) 2,250m, 3) 2,450m, and 4) 200m POST. The subject was a national level triathlete (age 21 years, height 179 cm, weight 67.5 Kg, fat mass 8.5%). Conditioning was assessed by HR values at submaximal effort (HR_{submax}), internal training load (ITL) was measured using the training impulse (TRIMP) method proposed by Banister (1991), external training load (ETL) was calculated multiplying total training distance by velocity and adding the product of elevation gained by gravity, the running ITL:ETL ratio was calculated dividing the mean ITL by the mean ETL of every period, resting heart rate variability was recorded every day upon waking, the square root of the mean sum of the squared differences between R-R intervals (rMSSD) was calculated and log transformed, $LnRMSSD_M$ and $LnRMSSD_{CV}$ parameters were also estimated. Relative to 200m PRE, running ITL:ETL ratio increased during 2,250m and 2,450m and reverted to baseline at 200m POST, $LnRMSSD_M$ was reduced below the SWC during the last week of 2,250m and throughout 2,450m, $LnRMSSD_{CV}$ was related to mean ITL and ITL A:C ratio across all four training periods, compared to 200m PRE, HR_{submax} was higher during 2,250 and 2,450 and lower in 200m POST. A monitoring protocol of ETL, ITL, $LnRMSSD_M$, $LnRMSSD_{CV}$, and HR_{submax} can be useful to evaluate the effectivity of altitude-training camps in sprint distance triathlon.

Key words: *Heart rate variability, TRIMP, Submaximal heart rate, Triathlon.*

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I. Introduction

Adequate assessment of autonomic nervous system (ANS) responses to training load (TL) during altitude camps can help understand performance enhancement mechanisms of elite level sprint distance triathletes. Sprint distance triathlon (SDT) includes consecutive phases of swimming (750m), cycling (20km), and running (5km) separated by brief transition periods. Competition tactics, like staying in the lead group whilst swimming, drafting in cycling, and positive strategies gives SDT a high-intensity-intermittent profile that must be considered when periodizing training (Bentley et al., 2008). To improve exercise capacity, the use of a live high – train high (LH – TH)altitude-training strategy is popular among SDT coaches, since it provides a short window of increased competition performance after returning to sea level (Rodríguez et al., 2015). Altitudes between 1800m and 3000m have been recommend for LH – TH, as higher altitudes may not be well-tolerated by athletes during rest or training because of sleep disturbances and performance limitations, respectively(Robach & Lundby, 2020).Accordingly, the2000 - 2500 m altitude range is reported as optimal (Nummela et al., 2021; Wilber et al., 2007).

When training at altitude, it is convenient that coaches use specific periodization tactics (Sharma et al., 2018)that consider several factors: altitude severity, duration of altitude stimulus, time lapses between altitude camps, athletes' altitude-training history, and timing in relation to competition (Saunders et al., 2019). It has been reported that a given external training load (ETL) during altitude-training produces a greater stimulus compared to when performed at sea level (Robach & Lundby, 2020). In this regard, coaches can adopt one of two approaches: a) maintain the same ETL as sea level which increases internal training load (ITL), therefore, risking chronic fatigue; or b) maintaining the same ITL as sea level reducing ETL (Friedmann-Bette, 2008). Decreasing ETL and not including high-intensity training sessions during the first 7-10 days of altitude camp has been recommended (Bahenský & Grosicki, 2021; Schmitt et al., 2018). Long-term periodization must include altitude-training camps and distribute them strategically in order to capitalize on the benefits during competitive periods (Mujika et al., 2019). Ideally, LH – TH altitude-training camps should culminate within two weeks before the competition (Mujika et al., 2019).

Nowadays, the use of heart rate variability (HRV) in triathlon training is increasingly accepted as a practical, noninvasive tool for autonomic nervous system (ANS) assessment (Plews et al., 2012). HRV monitoring can provide an evaluation of how athletes are coping with a novel stressor (i.e. altitude-training camp), providing coaches with insights for adjusting training programs on the individual level (Flatt & Esco, 2016). A 7-day rolling average of the natural logarithm of the root mean square of successive differences between normal heartbeats ($LnRMSSD_M$) and its coefficient of variation ($LnRMSSD_{CV}$) are among the most established HRV indexes in the scientific community as representative for ANS status (Plews et al., 2012; Plews et al., 2013) and an index of the impact of ITL or ETL on the athlete (Plews et al., 2012) respectively. HRV patterns for optimal performance have been commonly studied in normobaric training conditions. In high level endurance athletes, higher HRV during the overload phase (OL) and lower HRV during taper in the days or weeks before main competition is related to optimal performance (Plews et al., 2013). In contrast, sprint swimmers showed a pattern of reduced HRV during the OL period which reverts to baseline or higher after tapering, and may be indicative of optimum competition performance (Flatt et al., 2017). As far as we know, an ideal HRV pattern to altitude-training is not defined yet, as acute exposure to altitude is considered a confounding factor on longitudinal assessment. One study suggests that lower $LnRMSSD_M$ and $LnRMSSD_{CV}$ perturbations during week one of a 3-week 1655m altitude-training camp are related to positive responses (Altini et al., 2020). But a deeper evaluation on longitudinal HRV responses during altitude-training camps is required.

Therefore, the aim of this case study was to report the $LnRMSSD_M$ and $LnRMSSD_{CV}$ responses to ITL, ETL and performance from four 3-week training periods at altitudes of: 1) 200m PRE, 2) 2,250m, 3) 2,450m, and 4) 200m POST.

II. Methods

Participant

The subject was a national level triathlete (age 21 years, height 179 cm, weight 67.5 Kg, fat mass 8.5%). After being informed of the risks and requirements associated with the study, the subject provided written informed consent to participate in the case study. All proceedings conformed to the declaration of Helsinki.

Design and Procedures

Training periods. TL and HRV data were recorded during a 12-week period, divided into four 3-week mesocycles: a) Weeks 1-3, typical training at 200m altitude at the subject's hometown (200m PRE); this period was considered as baseline, b) Weeks 4-6 training at 2,250m altitude (2,250m), c) Weeks 7-9 training at 2,450m altitude (2,450m), and d) Weeks 10-12 return to typical training at 200m above sea level (200m POST). Only running or cycling sessions were programmed by the coaches during the study period. Weekly training configuration varied from week to week. An example of a typical training week is depicted in Table 1.

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

Submaximal test. Conditioning was assessed by HR values at submaximal effort (HR_{submax}). During testing days, the subject executed a 3.5 km run at 14 km/h as part of his warmup routine. 14 km/h was the selected submaximal effort because it was determined as the velocity at the first lactate threshold by an incremental test. The incremental test consisted of 3-minute effort stages interspersed by 1-minute rest periods running on a treadmill with 2% inclination. Starting speed was 6 km/h with 2 km/h increments at every stage until exhaustion. During the rest periods, capillary blood sample was taken from the fingertip and analyzed for blood lactate concentration using an Accutrend Plus device (Roche Diagnostics, Mannheim, Germany). First and second lactate thresholds were identified by Dmax method(Cheng et al., 1992).

Training load. Exercise HR and GPS distance was recorded every training session using a Garmin Vivoactive 3 device (Garmin International Inc., Olathe, USA). ITL was quantified on running and cycling sessions using the TRIMP Method proposed by Banister (1991). This method was calculated using the following equation:

$$TRIMP = t * \%HRres * 0.64 * e^{(1.92*\%HRres)}$$

Where t = time in minutes and %HRres represents HR reserve which is determined using the following equation:

$$\%HRres = (HR_{exe} - HR_{rest})/(HR_{max} - HR_{rest})$$

Where HR_{rest} = Average heart rate during rest, and HR_{exe}= the average heart rate during exercise.

For longitudinal analysis, the ITL acute:chronic (A:C) ratio was used. The ratio was calculated dividing the 7-day by the 30-day ITL rolling averages. This ratio shows a standardized ITL magnitude that indicates if the athlete is training above or below his usual values.

ETL was calculated only for running sessions for ITL:ETL ratio analysis purposes. ETL was calculated using the GPS distance using the following formula:

$$ETL = (d * v) + (EG * g)$$

Where d = session's total distance, v = velocity, calculated dividing distance by time, EG = elevation gained during the session, and g = gravity at 9.8 m/s^2.

The running ITL:ETL ratio was calculated for 200m PRE, 2,250m, 2,450m, and 200m POST, dividing the mean ITL by the mean ETL of every period.

Heart rate variability. The subject was instructed to record resting HRV every day upon waking in a seated position, fasted state, and spontaneous breathing using a Polar H10 (Polar electro Oy, Kempele, Finland) monitor connected by Bluetooth to a smartphone using the Elite HRV App. HRV values were taken from a 2-minute period after 1-minute stabilization. The R-R data series data was later exported to a computer for HRV analysis using Kubios software (University of Eastern Finland, Kuopio, Finland). Occasional artefact-noise was automatically corrected by the software's built-in filter (filter power = automatic). The square root of the mean sum of the squared differences between R-R intervals (rMSSD) was calculated and log transformed. $LnRMSSD_M$ and $LnRMSSD_{CV}$ parameters were also estimated.

Statistical Analysis

All descriptive values are presented as mean ± standard deviation (M ± SD). The magnitudes of standardized differences were assessed using Hedges' g effect sizes and were interpreted as: <0.20 = trivial, 0.20 - 0.60 = small, 0.6 - 1.20 = moderate, 1.20 - 2.0 large, >2.0 very large. The smallest worthwhile change (SWC) for $LnRMSSD_M$ was calculated as ± 0.5 of baseline CV. Associations between ITL and LnRMSSD parameters were assessed using Spearman correlation coefficient (Rho).

III. Results

Running ITL:ETL ratio comparisons between 200m PRE with 2,250m, 2,450m, and 200m POST are shown in Table 2.

******** Insert Table 2 here ********

Figure 1 shows $LnRMSSD_M$, $LnRMSSD_{CV}$, ITL A:C Ratio, and altitude values during the four 3-week periods.

******** Insert Figure 1 here ********

Significant associations were observed between $LnRMSSD_{CV}$ and mean ITL ($p < .05$, $\rho = .65$), and ITL A:C ratio ($p < .05$, $\rho = .69$). No associations were found between ITL parameters and $LnRMSSD_M$.

Compared to 200m PRE (144.75 ± 2.5), small differences of HR_{submax} with 2,250m (146 ± 7.21, ES = 0.25), very large with 2,450m (152.25 ± 2.06, ES = 3.27) and POST (139.66 ± 2.08, ES = -2.17) were detected.

IV. Discussion

The aim of this case study was to evaluate $LnRMSSD_M$ and $LnRMSSD_{CV}$ patterns relative to ITL, ETL and conditioning over four 3-week training periods at altitudes of 200m PRE, 2,250m, 2,450m, and 200m POST. The main findings were: 1) Relative to 200m PRE, running ITL:ETL ratio increased during 2,250m and 2,450m and reverted to baseline at 200m POST, 2) $LnRMSSD_M$ was reduced below the SWC during the last week of 2,250m and throughout2,450m,3) $LnRMSSD_{CV}$ was related to mean ITL and ITL A:C ratio across all four training periods, and 4) Compared to 200m PRE, HR_{submax} was higher during 2,250 and 2,450 and lower in 200m POST.

The present study showed small increases in ITL:ETL ratios in 2,250m and 2,450m (ES = 0.31, 0.32), representing 11.5% and 13.4% increments respectively compared with baseline. This is on agreement with the findings of Robach & Lundby (2020) demonstrating that ETL produced a greater internal stimulus at altitude. Increased ITL in response to similar ETLs is one of the factors SDT coaches need to address when periodizing for altitude. Particularly, in this case study, running ETL was maintained during 2,250m and elevated during 2,450m, which in turn, elevated running ITL over both periods. This appears to contradict the reduced ETL to match sea level ITL in the first week of altitude-training strategy that is commonly advised in the literature (Bahenský & Grosicki, 2021; Friedmann-Bette, 2008; Schmitt, Regnard, et al., 2018). Nonetheless, the weekly ITL A:C ratio of 2,250m and 2,450m periods, were 0.75 – 1.31 – 1.08 and 0.98 – 1.22 – 1.31 respectively, displaying what it appears to be adequate TL periodization, and demonstrates that indeed coaches reduced ITL during the first week of each altitude camp. Additionally, ITL:ETL returned to baseline values at 200m POST, suggesting that the added stimulus imposed by altitude is now removed.

The $LnRMSSD_M$ and $LnRMSSD_{CV}$ HRV indexes have been used to evaluate the impact of ITL or ETL (Plews et al., 2012). Reductions in $LnRMSSD_M$ have been used as a marker of TL response under the premise that high level athletes are supposed to recover from regular TLs within 24 hours (Stanley et al., 2013). In the present study, we observed constant reductions in $LnRMSSD_M$ below the SWC between week 3 of 2,250m and week 3 of 2,450m; Fittingly, early diminishing trends of $LnRMSSD_M$ seems to confirms that earlier stages of altitude-training incite greater HRV disturbances than regular training (Schmitt et al., 2018). Thus, reductions in $LnRMSSD_M$ can be attributed to exposure to altitude, possibly mediated by a reduction in plasma volume (Siebenmann et al., 2017). We observed a delayed reduction in $LnRMSSD_M$ below the SWC, which may be attributed to the periodization strategy of reduced ITL A:C ratio during week 1 of 2,250m, subsequently falling under the SWC after two consecutive weeks of ITL A:C ratio >1.0. Naturally, the intention of altitude-training is to increase the ITL stimulus (i.e., overload strategy) to produce functional overreaching. In this regard, a temporary reduction in $LnRMSSD_M$ is expected, and possibly desirable. $LnRMSSD_{CV}$ followed a similar pattern to ITL A:C ratio. However, during weeks 1 to 3 of 2,450m they showed an opposite trend. We considered this to be an adaptative response of the triathlete, enhancing his ability to cope with ITL during the latter part of altitude-training (Plews et al., 2012).

It is important to identify HRV trends in response to different periodization strategies that may be related to optimal performance or conditioning improvements; particularly, altitude-training strategies. The triathlete in the present study showed reductions in $LnRMSSD_M$ accompanied by elevations in $LnRMSSD_{CV}$ during the 2,450m, and an inverse trend towards the latter parts of altitude-training, and a return to baseline at 200m POST. There seems to be a correlation between increment in $LnRMSSD_M$ with gains in performance and fitness in moderate trained subjects during normobaric training conditions (Plews et al., 2013). Contrastingly, in high level endurance athletes, higher at OL and reduced during taper HRV in the days/weeks before main competition was related with optimal performance (Plews et al., 2013). Likewise, during an elite triathlete training, increases in LnRMSSD in response to block training was reported as indicative of positive adaptation and vice versa (Stanley et al., 2015). Yet, neither of these trends agreed with the present study. It is possible that the intermittent and high intensity nature of SDT was the reason for the apparent discrepancy in LnRMSSD indexes patterns between the present study and those of other elite endurance athletes. Usually, in elite endurance athletes we observe polarized periodization, characterized by high volumes and low intensities (i.e., at or below first lactate threshold) during OL and high intensities (i.e., at or above second lactate threshold) and low volumes during taper, which may explain the HRV responses. In this case, SDT training did not followed a polarized periodization model, and high intensity interval sessions were commonly used. Therefore, we believe that, for the SDT athlete in this case study, an optimal HRV pattern can have more similarities with those of sprint athletes. For example, the study on sprint swimmers, that showed that a pattern of reduced HRV on OL period and back to baseline or higher after taper and was related to optimum competition performance (Flatt et al., 2017).

Taking into account the effect of altitude to assess HRV responses in relation to performance, one study showed that during a 3-week 1655m altitude-training camp, lower $LnRMSSD_M$ and $LnRMSSD_{CV}$ perturbations on week 1were related to positive responses, represented by lower sub-maximal effort HR at week 3 (Altini et al., 2020). This is not completely in line with the present study. Even if the triathlete showed normal $LnRMSSD_M$ (within SWC) and low $LnRMSSD_{CV}$ (3%) during week 1 of 2,250m, the improvements in HR_{submax} did not manifested in the last week of altitude, but after returning to 200m POST. The lack of positive adaptation during the final week of 2,450m can be explained by elevated ITL A:C ratios during the final two weeks of 2,450m (1.21 and 1.31 respectively), indicating that the subject was exposed to higher-than-normal TLs. Positive adaptation (i.e., lower HR_{submax}) occurred after reductions in ITL A:C ratios in weeks 1 and 2 (0.63 and 0.35 respectively) of 200m POST, which can be considered a taper strategy. Additionally, if coaches need to manage TL to regulate ANS responses to early altitude hypoxia, an HRV-guided program can be adequate. On endurance athletes, this approach has been demonstrated to reduce HRV perturbations in comparison with inflexible programs (Sanz-Quinto et al., 2018; Schmitt et al., 2018) and produce greater performance gains at moderate altitude (Bahenský & Grosicki, 2021).

In the present study, across all the four 3-week camps weekly mean ITL and ITL A:C Ratio were related to $LnRMSSD_{CV}$ but not to $LnRMSSD_M$. These findings are in line with Impellizzeri et al. (2018), who states that $LnRMSSD_M$ is not an indicator of ITL, since this responses occur after, and not during, exercise. Therefore, this metric is considered as a subrogate response to ITL. Furthermore, data appear to confirm that $LnRMSSD_M$ reductions below SWC indicate a desired state of accumulated fatigue (i.e., functional overreaching) induced by repeated exposition to high ITL in altitude, allowing the coaches to assess the triathlete's ANS state in response to ITL and adjust the training program if deemed necessary. Also, the presented data agrees with what was reported by Flatt & Esco (2015) in intercollegiate female soccer players, that daily fluctuations in HRV appear to be greater during a week of higher TL, while weekly mean values only demonstrated small changes. This fact reinforces the notion that HRV responses of an SDT athlete have more in common with intermittent sport athletes. Apparently, $LnRMSSD_{CV}$ will be higher when the athlete is exposed to higher ITLs than what he is accustomed to, which can be easily evaluated by the ITL A:C Ratio.

The triathlete in the present study, after a 3-week training phase at 200m, underwent two consecutive 3-week LH – TH altitude-training camps at 2,250m and 2,450m respectively, and later returned to 200m. A live high – train low altitude-training strategy is considered to be more effective for enhancing sea level performance

(Rodríguez & Ávila, 2018), Nevertheless, a LH – TH strategy appears to be more popular among SDT coaches. The subject seemed to improve his conditioning, characterized by a reduction in HR_{submax} at 200m POST. We believe that this improvements are triggered by altitude exposure performance-related adaptation mechanisms like: pulmonary ventilation increase by carotid activation within minutes, plasma volume reduction to raise hemoglobin (Hgb) concentration after several days, and a raise in red blood cell count triggered by erythropoietin (EPO) secretion within weeks (Robach & Lundby, 2020). Moreover, there also can be non-hematological adaptations to altitude-training like mitochondrial gene expression and increased buffering capacity in the muscle (Mujika et al., 2019); Also, improvements in performance could have been mediated via placebo effect when training at altitude (Rodríguez & Ávila, 2018). To assess positive training adaptation, coaches, scientists, and practitioners seek to use time-efficient methods that do not detract from practice time. That is why sub-maximal effort tests are a viable option. We consider HR_{submax} data as an indicator of fitness level, VO_2max, and aerobic capacity (Lamberts et al., 2011). These HR_{submax} values are reported to predict endurance performance (Buchheit et al., 2010; Lamberts et al., 2011). A typical positive adaptation pattern during an altitude training camp shows a larger initial HR for a given exercise, and gradually decreasing towards sea level values approaching the training camp's end (Altini et al., 2020). Thus, sub-maximal HR can be an ideal method for longitudinal responses during an altitude training camp.

V. Conclusions

Coaches can measure the internal effect of altitude using the ITL:ETL ratio, since it gives an objective measure of the relative increment of the stimulus. A combined analysis of $LnRMSSD_M$ and $LnRMSSD_{CV}$ can provide information about both the athlete's fitness/fatigue status, and TL coping ability respectively, during an altitude-training program. A recovery pattern in $LnRMSSD_{CV}$ in the latter parts of an altitude-training program suggests positive adaptation despite reduced $LnRMSSD_M$ below SWC. The use of HR_{submax} during warmup can be a convenient tool for conditioning assessment without affecting training time. A monitoring protocol of ETL, ITL, $LnRMSSD_M$, $LnRMSSD_{CV}$, and HR_{submax} can be useful to evaluate the effectivity of altitude-training camps in SDT.

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Table 1
Depiction of a typical training week

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
50 km Cycling 10 km Running	15 x 200m HIIT Running	50 Km Cycling 10 km Running	5 x 600m HIIT Running	Rest	18 Km Running	50 Km Cycling

Note.HIIT = High intensity interval training.

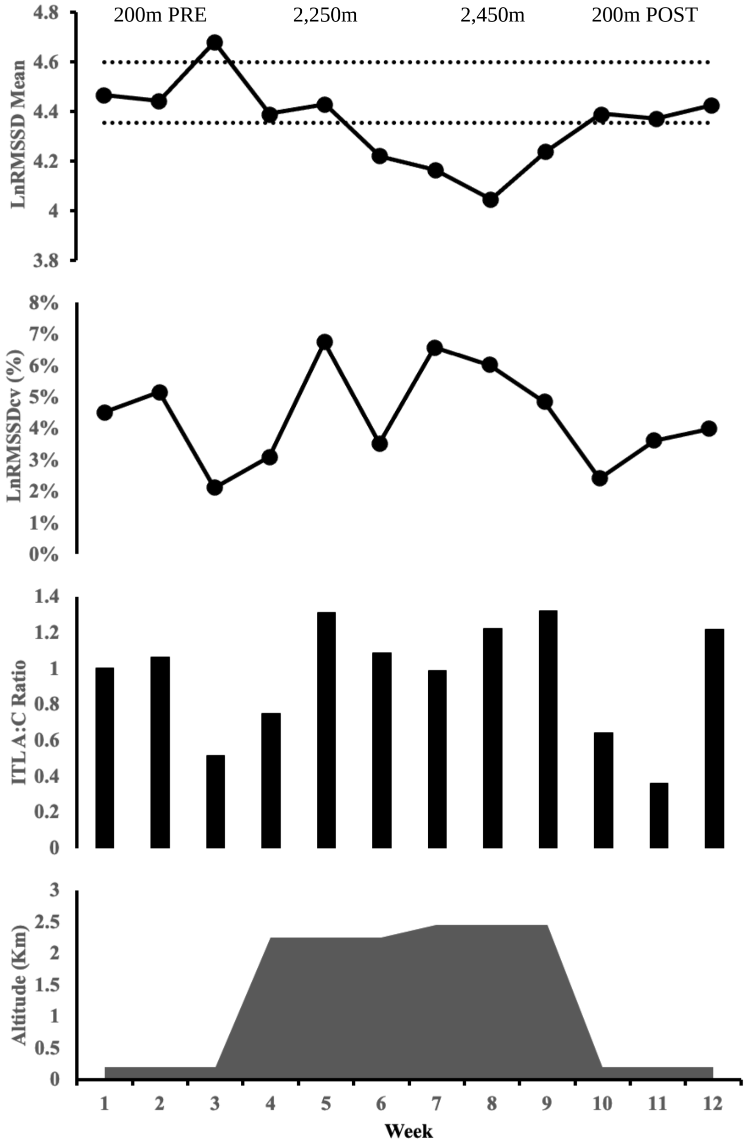
Table 2
Running ITL, ETL and ITL:ETL ratio comparisons

Period	Running ITL	Running ETL	Running ITL:ETL Ratio	ES	Qualitative
200m PRE	62.91 ± 42.78	122.46 ± 83.42	0.52 ± 0.15	- -	- -
2,250m	69.80 ± 55.47	122.03 ± 86.67	0.58 ± 0.17	0.31	Small
2,450m	78.54 ± 48.56	144.16 ± 92.30	0.59 ± 0.25	0.32	Small
200m POST	50.00 ± 50.25	92.36 ± 88.07	0.53 ± 0.10	0.06	Trivial

Note. ES analysis shows magnitude of change of ITL:ETL ratio vs PRE.

Figure 1

LnRMSSD$_M$, LnRMSSD$_{CV}$, ITL A:C Ratio, and altitude values across the four 3-week periods.



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