HR, Velocity Selection and PO_2 during RPE Production at Sea Level vs. Altitude

James M. Green[1*], Jeffrey D. Simpson[2], and Brandon L. Miller[3]

[1]Department of Kinesiology, University of North Alabama, USA

[2]Department of Movement Sciences and Health, University of West Florida, USA

[3]New Balance, USA

Abstract

Acutely, altitude may disrupt RPE association with sea level physiological responses, potentially altering workload selection during RPE production. To assess the impact of altitude on perceptually anchored intensity regulation. Males (n=6) and females (n=6) (VO_2 max = 50.1 + 7.8 ml·kg-1·min-1) completed counterbalanced production trials at sea level (SEA) and altitude (ALT, ~3400m) at RPE 4 and RPE 7, blinded to velocity (VEL) (1% grade). ANOVA's (trial x RPE) showed no significant difference for VEL (m·min-1) within RPE 4 (SEA = 186 ± 23, ALT = 190 ± 29) or RPE 7 (SEA = 253 ± 31, ALT = 255 ± 40). However, PO_2 (%) was significantly lower for ALT within RPE 4 (96.4 ± 2.0 vs. 83.5 ± 5.4) and RPE 7 (97.2 ± 0.9 vs. 83.1 ± 3.4). HR (b·min-1) was significantly higher for ALT within RPE 4 (133 ± 19 vs. 153 ± 17), and RPE 7 (163 ± 18 vs. 175 ± 12). Session RPE was not significantly different between SEA and ALT within RPE 4 (ALT = 3.9 ± 0.8, SEA = 3.7 ± 0.7) or RPE 7 (ALT = 6.7 ± 0.5, SEA = 6.8 ± 0.8). Physiological variables (HR, PO_2) seem subsidiary to workload (VEL) in mediating the RPE production paradigm at altitude with those observations consistent for Session RPE. Correspondence between perceptual responses and other physiological factors, (lactate, VO_2, etc) at altitude warrants further consideration including responses across varying fitness levels, exercise modalities and following acclimatization periods.

Keywords: Perception; Training; Running; Intensity Regulation; Ratings of Perceived Exertion.

INTRODUCTION

Perceptual responses allow assessment of subjective responses to exercise including in-task (i.e. acute) RPE [1], and estimations linked with the entirety of a bout (i.e. Session RPE) [2]. Laurent, Green, Bishop, Sjökvist, Schumacker, Richardson and Curtner-Smith et al. [3], developed the Perceived Recovery Scale (PRS) to permit estimated feelings of recovery prior to an exercise bout. RPE also allows intensity regulation where individuals adjust effort to generate a prescribed feeling of exertion (RPE-production). In this paradigm, Glass, Knowlton and Becque et al. [4], found no significant differences for ventilation or VO_2 at RPE associated with 75% HR. Dunbar, Robertson, Baun, Blandin Metz and Burdett et al. [5], found no significant difference for HR or VO_2 at 50% maximal VO_2, but significantly lower values during production at 70% VO_2 max. Similar to Glass, Knowlton and Becque et al. [4], Green, Michael and Solomon et al. [6], observed HR correspondence (estimation vs. production) at higher (RPE 16) but not lower perceptually prescribed swimming intensities. These and others [7], support Robertson and Noble et al. [1], that though inconsistencies exist, the estimation-production paradigm is generally effective for intensity regulation.

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***Corresponding author(s):** JM Green, University of North Alabama, Department of Kinesiology, 1 Harrison Plaza, UNA Box 5073, Florence, AL 35632, USA, Tel: (256) 765-4554

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Perceptual responses are mediated by a myriad of factors [1]. It is plausible that the exercise paradigm is important when identifying dominant factors. While acute RPE and blood lactate may be coupled during graded testing [8-10], a clear divergence is likely during constant-load [11], and interval exercise [12]. Importantly, constant load and interval exercise more effectively mimics daily training (vs. graded 'maximal' testing). Green, Zhang, Laurent, Davis Kerr Pritchett and Bishop et al. [12], also showed RPE is sensitive to (hot vs.cool) environment, an unpredictable component of daily training. Pandolf [13], suggested that hypoxia associated with high altitude contributed to elevated lactate which had a major influence on RPE. Altitude alters oxygen partial pressure potentially impeding aerobic performance. Young, Cymerman and Pandolf et al. [14], concluded central rather than peripheral factors mediate perceptual responses at altitude. Prior to excessive ventilatory strain, local factors may dominate RPE while ventilatory responses are more important as intensity increases [15]. The function of RPE for self-regulation of intensity hinges in part on mediating factors. Reviews are available outlining physiological responses to exercise at altitude [16,17], and it is plausible that some of these may alter workload dependent physiological factors mediating RPE or disrupt the RPE-workload correspondence. Williams, Bell, Jacobs and Subudhi et al. [18], concluded that changes in inspired oxygen at simulated moderate altitude did not alter RPE-based power selection at perceptual prescriptions < 13. Jeffries, Patterson and Waldron [19], suggested that progressive arterial hypoxemia and elevated ventilation are principal factors mediating RPE. In that study the paradigm was a clamped RPE of 16. Williams, Bell, Jacobs and Subudhi et al. [18], and Jeffries, Patterson and Waldron et al. [19], simulated altitude by augmenting inspired O_2. These studies have extended the understanding of effects of altitude on perceptual responses, however, perceptually based intensity at altitude is not well understood. Subjective responses such as perceived exertion minimize need for assessment of often tedious, invasive and sometimes costly physiological variables. Daily intensity regulation is convenient using a perceptual model, yet convenience should not supersede validity. The physiological congruence between perceptually regulated exercise at sea level vs. altitude has not been established. While much is known about altitude training and acute physiological responses, the influence of altitude on perceptual responses is unclear. In particular, few studies to date have examined influence of altitude on RPE as a tool for exercise prescription. This study examined velocity selection and corresponding HR and PO_2 response during treadmill exercise at sea level vs. altitude.

MATERIALS AND METHODS

Participants and Descriptive Data

Individuals including male (n = 6) and female (n = 6) students volunteered as participants. All reported being recreationally active, were screened with the PAR-Q [20], and presented minimal risk for cardiovascular incident during exercise based on known risk factors. Participants were assessed for descriptive data including age (yr), height (cm) using a stadiometer (Invicta Plastics Limited, Leicester, England), mass (kg) using a Tanita digital scale (Tanita, Tokyo, Japan) and body fat percentage using Lange skinfold calipers (Lange, Cambridge, MD) and a 3-site method (males: chest, abdomen, thigh, females: tricep iliac crest, thigh) [21]. All procedures were approved by the appropriate university review board for the protection of human subjects and all participants signed written informed consented voluntarily prior to initiation of data collection. Data for analyses in this study will be made available on reasonable request.

VO_2 max Session

Following descriptive data during the initial lab session, participants completed a graded test on a Trackmaster motor-driven treadmill (Vacu-med, Ventura, CA) to assess maximal oxygen consumption (VO_2 max). The protocol adhered to the following velocity (m·min-1) and grade combinations: 81:0 %, 107:0 %, 134:0 %, 161:0 %, 188:0 %. Once achieving 188 m·min-1, velocity was constant and grade increased 2 % per min until participants achieved volitional exhaustion or investigators deemed it unsafe. Participants were fitted with a Polar Heart Rate Monitor (Stamford, CT) and an air-cushioned face mask (Vacu-med, Ventura, CA) integrated with a Vacu-med metabolic system (Vacu-med, Ventura, CA) which was calibrated prior to testing using a gas of known concentration and a 3 L syringe (Hans Rudolph, Shawnee, KS). The system was set to provide metabolic data averaged across 20s intervals. The highest value observed during the test was recorded as VO_2 max. During the test, participants estimated overall RPE each min using the previously validated [22], Omni RPE scale.

RPE Production Trials

Following VO_2 max determination, participants completed two RPE production trials. One trial was completed at ~167 m above sea level (Florence, AL) and the other at ~3400 m above sea level altitude (Cusco, Peru). To counterbalance RPE production trials, half of the participants completed the sea level trial prior to traveling to altitude and half completed the sea level trial upon return from altitude. All participants completed RPE production trial at altitude collectively.

RPE production trials involved participants donning a heart rate monitor (Polar, Stamford, CT) and a pulse oximeter (ChoiceMMed, Beijing, China) for assessment of oxygen saturation (PO_2). Treadmill grade was 1% to mimic outdoor exercise (Jones and Doust 1996) for these trials and participants were blinded to treadmill velocity as well as HR and PO_2. Participants familiarized themselves with the treadmill during a 2 min warm-up completed at a self-selected workload. Participants were made aware before starting production trials that, at the completion of the warm up they would have three minutes to adjust the velocity of the treadmill to achieve a workload corresponding to RPE 4 based on feelings of exertion. Upon achieving production of RPE 4, participants exercised on the treadmill at that velocity (1% grade) for 5 min with HR and PO_2 recorded each min. Participants completed the RPE 4 production and then completed a 10 min passive recovery and estimated a Session RPE (S-RPE) for that portion of the trial. Following recovery, participants returned to the treadmill and completed RPE 7 production in the same manner (2 min warm up, 3 min adjustment period, 5 min constant load) with HR and PO_2 recorded each min. Following completion of RPE 7 production, participants completed a second passive recovery after which they estimated Session RPE. Treadmill velocity was recorded per each participant for RPE 4 and RPE 7 production trials.

Statistics

Dependent measures of HR and PO_2 were recorded each minute during the 5 min production trials for ALT and SEA at RPE 4 and RPE 7. Mean values were calculated by taking the average of the five recorded values per respective trial per participant. These means were taken as representations of the best reflection of the overall responses during the production periods and analyzed using a 2 (environment) x 2 (RPE level) repeated measures ANOVA for each dependent measure. Treadmill velocity selection (VEL) during production periods did not change throughout and therefore calculation of a mean was not necessary. VEL was analyzed using a 2 (environment) x 2 (RPE level) repeated measures ANOVA. When necessary, follow-up t-tests were conducted. To assess agreement between VEL (SEA vs. ALT) Bland-Altman plots [23],

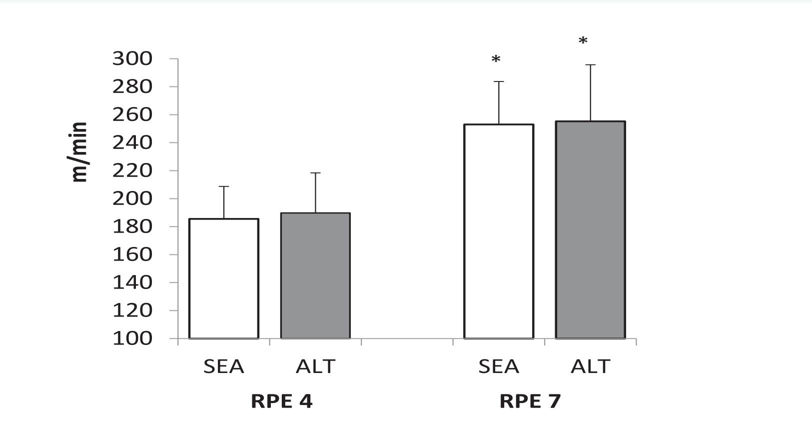

Figure 1: Velocity selection (VEL) (m·min-1) for SEA and ALT for RPE 4 and RPE 7. Values are means and standard deviations. *$p \leq 0.05$ RPE 4 vs. RPE 7 within SEA and within ALT

were created for RPE 4 and RPE 7. S-RPE was compared between ALT and SEA within RPE 4 and RPE 7 using a paired t-test for each intensity level. Results were considered significant at $p \leq 0.05$.

RESULTS

Descriptive characteristics are presented in Table 1. For VEL there was no significant main effect for environment (ALT vs. SEA) and no significant interaction but there was a significant main effect for RPE level (Figure 1). Follow up tests showed a significantly faster VEL for RPE 7 vs. RPE 4 within ALT as well as within SEA (Table 2). For HR there was a significant main effect for environment as well as RPE level but no significant interaction. Follow-up tests showed a significantly greater HR for ALT within RPE 4 and within RPE 7 trials (Figure 2), and HR was significantly greater for RPE 7 vs. RPE 4 for ALT as well as SEA (Figure 2). For PO_2, there was a significant main effect for environment (ALT vs. SEA) but no significant main effect for RPE level and no significant interaction. Follow up tests showed significantly lower PO_2 for ALT than SEA within RPE 4 and within RPE 7 (Table 2). For SRPE there was no significant difference within RPE 4 (ALT: 3.9 ± 0.8, SEA: 3.7 ± 0.7, p= 0.08) or within RPE 7 (ALT = 6.7 ± 0.5, SEA = 6.8 ± 0.8, p = 0.59). Testing for ALT was completed in a single afternoon with dry bulb temperature recorded at 18.3, wet bulb at 21.1 and humidity at 76%. For SEA testing was completed on three separate testing days with the mean values relative to environment for these three days being; dry bulb (18.9 ± 0.6), wet bulb (17.2 ± 0.6) and humidity (73 ± 9%).

DISCUSSION

Perceptual models optimize convenience when assessing pending fatigue as during a GXT while also minimizing need for assessing physiological variables to identify desired workloads or intensity zones. A myriad of mediating factors may alter perceived exertion [1], to form a Gestalt response. With many mediating factors being physiological, acute issues, which alter physiological responses, may concurrently change perceptual responses. It is plausible that acute altitude exposure may alter a diverse set of physiological factors during exercise potentially altering perceptual responses. This may include elevated RPE estimations at set workloads and altered workload selection for RPE-based intensity prescriptions (i.e. RPE production). However, this is not well-understood particularly regarding the influence of altitude on the RPE production model. This study compared velocity selection and corresponding HR and PO_2 between treadmill trials performed at sea level and altitude at prescribed numerical RPE values.

Current results show no significant difference in VEL selection

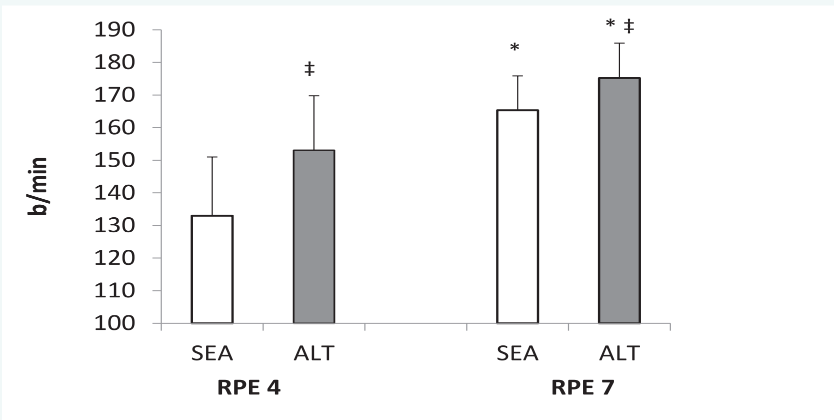

Figure 2: Heart rate (HR) response for SEA ALT for RPE 4 and RPE 7. Values are means and standard deviations. *$p \leq 0.05$ RPE 4 vs. RPE 7 within SEA and within ALT, ‡$p < 0.05$ SEA vs. ALT within RPE 4 and within RPE 7

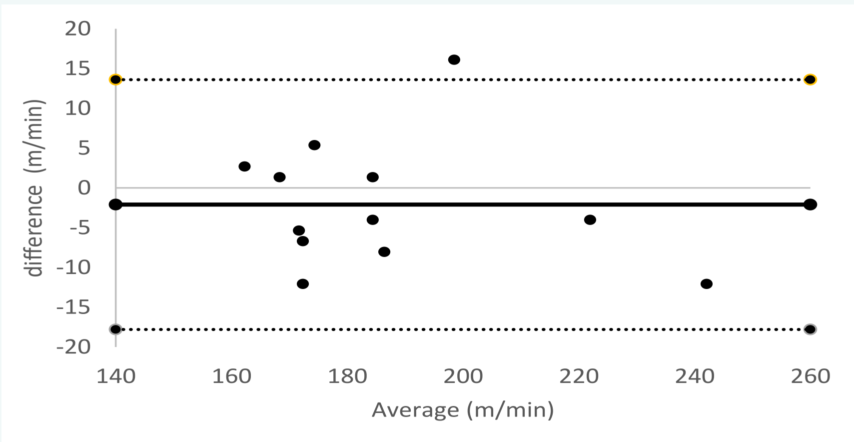

Figure 3: Bland-Altman plot for velocity for RPE 4.

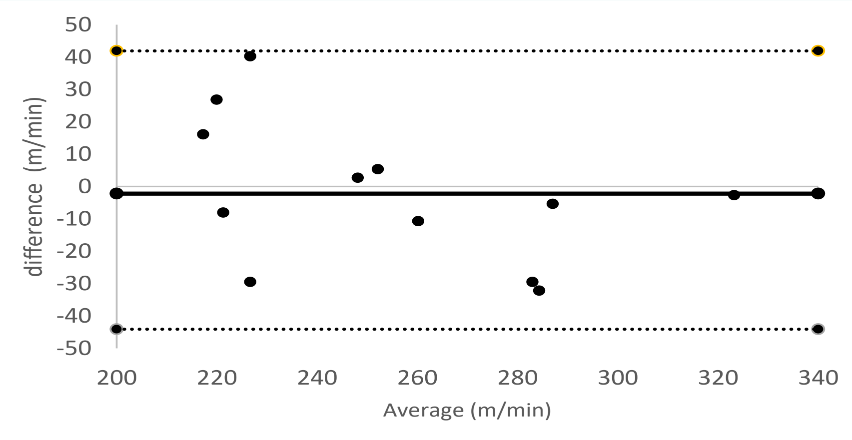

Figure 4: Bland-Altman plot for velocity for RPE 7.

Table 1: Descriptive characteristics of participants (n = 12).

Variable	Mean (sd)
Age (y)	21.9 ± 1.7
Ht (cm)	171.7 ± 9.1
Mass (kg)	70.5 ± 15.0
Percent fat	17.5 ± 7.0
Maximal HR ($b{\cdot}min^{-1}$)	191 ± 6
VO_2 max ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	50.1 ± 7.8

Table 2: Oxygen saturation (PO2) for (SEA) and (ALT) for RPE 4 and RPE 7. Values are means and standard deviations.

	SEA	ALT
RPE4	96.4 ± 2.0	83.5 ± 5.4 *
RPE7	97.2 ± 0.9	83.1 ± 3.4 *

*p ≤ 0.05 SEA vs. ALT within RPE production trial

NSD: RPE 4 vs. RPE 7 within SEA and within ALT

between ALT and SEA trials within prescribed intensity of RPE 4 or prescribed intensity RPE 7 (Figure 1). Similarity is also supported by Bland-Altman plots (Figure 3 and Figure 4). The lack of systematic change in velocity selection in the current paradigm suggests RPE is a robust model for achieving a prescribed workload, in this case treadmill velocity, even when transitioning to altitude. Alterations in HR (Figure 2), and particularly PO_2 (Table 2), suggest the altitude was severe enough that participants experienced a meaningful physiological challenge (vs. sea level work). Even so, selected velocities were not significantly altered (Figure 1). It would be anticipated that a greater physiological challenge would result in a systematic adjustment in the perceptually regulated workload. However, in the current study, this was not observed. Young, Cymerman and Pandolf et al. [14], showed 27% lower VO_2 max values associated with simulated (hypobaric chamber) acute high-altitude exposure. In that study, estimated local RPE at given percentages of environment-specific VO_2 max within the acute exposure period were unchanged from sea level responses even though during altitude exposure there was a reduced absolute workload required to achieve the target relative intensity (85% environment specific VO_2 max). Those results suggest RPE estimations may be closely linked with relative physiological responses. Environment specific VO_2 max values were not assessed in the current study. However, significantly reduced PO_2 (Table 2), and significantly elevated HR (Figure 2), during acute altitude exposure failed to disrupt the alignment between RPE and velocity observed for SEA when using RPE production. Within this model, current results indicate workload is a stronger mediator than physiological variables (HR and PO_2).

Robertson and Noble [1], proposed that perceptual responses are a Gestalt with input from numerous mediating factors and that the dominating factor may also hinge on multiple factors. For example, the contribution of ventilation toward RPE transitions from low to moderate to high as intensity increases [15]. While lactate has been implicated as a mediating factor [8-10], Green, McLester, Crews, Wickwire, Pritchett and Redden et al. [11], showed a clear divergence between RPE and lactate suggesting the importance is either mild or limited in scope. With multiple potential mediating factors and situation-dependent dynamic relative contributions each, it is reasonable to conclude a parallel paradigm exists at altitude. That is, no single factor remains universally dominant, nor are the relative contributions from specific factors unchanging. Young, Cymerman and Pandolf et al. [14], concluded that central more so than peripheral factors mediate perceptual responses at altitude. While physiological variables assessed in the current study (HR, PO_2) were significantly altered in a predictable manner on ascent to altitude, RPE-based workload selection was not, suggesting velocity and workload are more critical to producing a prescribed RPE than are physiological responses. However, the link between perceptual responses and contribution/dominance of different physiological input is volatile as conditions change, and thus whether observations from the current study would remain consistent outside the testing conditions (altitude level, participant fitness, temperature/environment, intensities, etc), is unclear. Additional work is necessary at different altitudes, with individuals with different fitness levels and for intensities outside those tested. Likewise, it is plausible that physiological variables other than PO_2 and HR that were not measured in the current study were relevant with respect to the consistency between RPE and velocity selection. Including additional physiological variables in future work would extend the understanding of the impact of altitude on perceptual responses.

Current participants were screened to assure absence of meaningful health disparities that might prohibit participation and none were identified. Further, mean VO_2 max (Table 1), values indicate they were recreationally active. It is possible that this group of participants were decidedly accustomed to the treadmill velocity associated with their daily exercise regimen and therefore velocities they preferred could have dominated perceived exertion more than associated physiological changes. Highly fit runners arguably may be more rigid (vs. recreationally active individuals) with respect to including diverse workouts as part of their training schedule. That is, they would be more apt to include interval workouts, long slow distance workouts, and other types of training. Exposure to undulating types of training could lead participants to rely more heavily on feedback from central and peripheral sensations in formulating the perceptual response rather than adjusting velocity to what might be 'comfortable' and typical of regular training. If so, highly fit runners may present different results than those of the current study. Though speculative, this is worthy of future inquiry.

Individual responses are important to consider in many studies. Should a portion of participants respond positively while a similar proportion respond negatively or not at all, aggregate statistical analyses could suggest no significant differences potentially creating misleading conclusions. If divergent responses occur in a group of participants, scientists should defend against such an occurrence masking true results for individual participants. Accordingly, some individual's performance may be impaired comparatively less at altitude than others. Consequently, we reviewed individual responses. A more in-depth assessment however did little to suggest any true effect was hidden. Of 24 observations (12 participants, two intensities) only two occurrences (two different participants) were identified in which the velocity difference (ALT vs. SEA) was meaningful (exceeded one standard deviation). In addition, individual velocity deviations (ALT vs. SEA) were relatively small with ten observations showing slightly lower velocity for ALT and 14 slightly higher for ALT. In each case the magnitude of the difference was trivial. Therefore, consideration of the individual responses further supports the conclusions derived from the aggregate analyses in the current study.

Session RPE (S-RPE) reflects the totality of a workout [2]. Several investigations have sought to identify factors which alter or mediate S-RPE. Caffeine has been implicated [24], as well as environment and workout type (interval vs. constant load) [12]. The influence of altitude on S-RPE is not well-understood. S-RPE in the current study was estimated by participants following completion of both intensity production trials (RPE 4 and RPE 7). While production trials fail to simulate a workout typical for a recreationally fit exerciser, lack of significant velocity differences does effectively isolate the influence of altitude on S-RPE. There were no significant S-RPE differences between ALT and SEA within RPE 4 (ALT: 3.9 ± 0.8, SEA: 3.7 ± 0.7), or RPE 7 (ALT = 6.7 ± 0.5, SEA = 6.8 ± 0.8). With no significant velocity difference and a clamped treadmill grade (1%) energy expenditure (ALT vs. SEA) is speculated to have been similar. Of note, VO_2 during production trials was not assessed due to equipment constraints especially at altitude. Also, with a standard duration for production trials, total work (ALT vs. SEA) would have been comparable. From these assumptions, acute intensity and total work completed may be linked with S-RPE more so than changes in physiological responses (HR, PO_2). Regarding individual responses, of 24 observations, five (three for RPE 4, two for RPE 7) (~21%) resulted in a one-unit higher S-RPE (10 pt scale) for ALT. These five observations occurred in five different participants. More work is warranted to determine if S-RPE is systematically elevated as a result of transitioning to altitude. Of particular importance would be to investigate the interaction of intensity and duration at sea level vs. altitude and assess S-RPE following exercise bouts typical for daily training.

CONCLUSIONS

In summary, current results indicate that, in recreationally fit males (n=6) and females (n=6), altitude-based changes in HR and PO_2 are subsidiary to treadmill velocity with regard to intensity production using RPE. These results hold true for lower (RPE 4) and higher (RPE 7) intensities. Similarly, S-RPE was not significantly different (ALT vs. SEA) suggesting acute physiological changes (PO_2, HR) are of minimal importance to this global perceptual measure. Within limitations of the current study, recreationally active individuals transitioning from sea level to altitude can confidently rely on RPE to replicate treadmill training velocity. More work is warranted to extend the knowledge regarding effective use of perceptual responses (estimation and production) at sea level vs. altitude. Of particular importance would be the potential link between perceived exertion and physiological variables, across different exercise types and participant fitness levels.

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AUTHOR CONTRIBUTIONS

All authors contributed the study conception and design. Material preparation, and manuscript preparation were complete by JM Green with assistant from J Simpson. Data collection was completed by Green, Simpson and Miller with all authors contributing to final manuscript.

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