



Effects of Caffeine on Perceptually-Based Intensity Production During Outdoor Running

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ABSTRACT

International Journal of Exercise Science 12(5): 526-535, 2019. Caffeine (CAF) may enhance performance while altering estimated RPE. However, effects of caffeine on RPE production is not well understood. This study examined effects of CAF on velocity (VEL) selection during outdoor running when intensity was prescribed using RPE. Ten ($n = 10$) fit male runners completed a VO_2 max and two running trials, CAF ($6 \text{ mg} \cdot \text{kg}^{-1}$) vs. placebo (PLA). Participants ran a 2.4 km (1.5 m) bout, at prescribed RPE4, and another at prescribed RPE7, following 10 min passive recovery. Separate 2 (trial) \times 6 (time point) repeated measures ANOVA's compared CAF vs. PLA for VEL and heart rate (HR). No significant main effect was found (CAF vs. PLA) for VEL ($\text{m} \cdot \text{min}^{-1}$) for RPE4 (CAF: 201.7 ± 25.8 vs. PLA: 196.0 ± 17.5) ($p = 0.29$) or RPE7 (CAF: 236.7 ± 19.5 vs. PLA: 231.8 ± 21.3) ($p = 0.30$). Similarly, no main effect was found (CAF vs. PLA) for HR for RPE4 (CAF: 163 ± 12 vs. PLA: 162 ± 14) ($p = 0.69$) or RPE7 (CAF: 181 ± 7 vs. PLA: 178 ± 10) ($p = 0.31$). No significant difference was found for Session-RPE for RPE4 (CAF: 4.0 ± 0.00 , PLA: 4.20 ± 0.42) ($p = 0.17$), however, Session-RPE for RPE7 CAF (7.10 ± 0.32) was significantly lower than PLA (7.50 ± 0.53) ($p = 0.04$). While group means show no significant differences, 9 of 20 total trials (45%) were 26 to 104 sec faster for CAF (mean difference = 54 sec) demonstrating improvement in select individuals. Future research should focus on varying responses of individuals to CAF.

KEY WORDS: Training, RPE production, exercise

INTRODUCTION

Ratings of perceived exertion (RPE) (4) allow subjective estimation of exertion and can be used for intensity prescription and regulation (26). In the estimation-production paradigm, an exerciser produces a prescribed RPE or range of RPE's (i.e. "5-8") analogous to a prescribed heart rate range by self-adjusting effort level until the exercise feels like the prescribed RPE. Although inconsistencies can be found, research generally supports RPE as effective for intensity regulation and prescription (10, 16, 20, 26). An additional application is use of Session RPE (12) which permits a post-exercise subjective assessment of the global difficulty of an exercise bout.

Research indicates caffeine can be an effective ergogenic aid. Dosages of $3\text{-}9 \text{ mg} \cdot \text{kg}^{-1}$ benefits aerobic (3, 14, 23) and anaerobic (5, 7, 9, 11, 18, 19) exercise. Potential ergogenic mechanisms

include decreased pain perception and enhanced free fatty acid mobilization (6, 7, 15). Previous studies have also shown blunted RPE estimations during exercise after caffeine ingestion (3, 9, 18, 21) with this effect likely attributed to a blockade of A1 and/or A2 receptors which inhibits feelings of pain (13).

While caffeine has been shown to mitigate acute RPE estimations (3, 9, 18, 21), effects on perceptually-based intensity production is not well-understood. Cole et al. (6) prescribed specific RPE values and found a significantly higher cumulative work volume for three consecutive 10 min cycling bouts following caffeine (277.8 ± 26.1 kJ) vs. placebo (246.7 ± 21.5 kJ) ingestion. Similarly, Langford et al. (22) (unpublished observation) reported significantly higher workload selection and associated physiological responses (HR, blood lactate) at prescribed RPE's of 4 and 7 following caffeine (vs. placebo) ingestion. These studies suggest caffeine may result in selection of higher cycling workloads when the prescription is made using RPE. Cole (6) and Langford (22) examined stationary cycling as an exercise mode; however, running (treadmill or over-ground) has not been investigated in this paradigm. From an exercise prescription standpoint it is important to know if acute caffeine ingestion alters self-selected running velocity. No study to date has investigated effects of caffeine on prescribed RPE in an ecologically valid paradigm. This study examined effects of caffeine (vs. placebo) on velocity selection and HR response during outdoor running at prescribed RPE values of 4 and 7.

METHODS

Participants

Based on a power analysis using $\beta = 0.8$, $\alpha = 0.05$ and an effect size of 4 sec (per quarter mile) (0.5 Cohen's *d*) between CAF and PLA trials, ten fit male participants were recruited. Participants were excluded if they were not engaged in running (≥ 10 miles/wk) at the time of the study or if screening (using known ACSM risk factors) indicated presence of potential health issues. Prior to data collection, procedures were approved by the local review board for protection of human subjects and participants completed a written informed consent outlining requirements. Participants reported to the lab well hydrated, having abstained from exercise, alcohol and caffeine in the 24 h prior to each session. Descriptive information was assessed including age (y), height (cm) using a stadiometer (Invicta Plastics Limited, Leicester, England) and mass (kg) with the latter measured using a digital scale (Tanita Corporation, Japan). Skinfold calipers (Lange, Cambridge, Md, USA) were used to estimate body fat percentage with a 3-site] method (chest, abdomen, thigh) (24). Participants completed a survey to assess average daily caffeine consumption.

Protocol

Following descriptive characteristics, participants donned a heart rate (HR) monitor transmitter (Polar, Stamford, CT, USA) at the level of the sternum and an appropriately-sized air-cushioned face-mask (Vacu-med, Ventura, CA) and completed an incremental test on a motor-driven treadmill (Quinton, Bothell, WA) to determine maximal oxygen consumption (VO_2 max). The protocol adhered to the following velocity ($\text{m}\cdot\text{min}^{-1}$) and grade combinations: 81:0%, 107:0%, 134:0%, 161:0%, 188:0%. Once achieving $188 \text{ m}\cdot\text{min}^{-1}$, velocity was constant and grade increased

2% per min until participants achieved volitional exhaustion or investigators deemed it unsafe. Metabolic data were measured using a metabolic measurement system (Vacumed Vista minicpx (silver) Vacu•med, Ventura, CA,) calibrated prior to each test with a gas of known composition and a 3 L syringe (Hans Rudolph, Kansas City, MO). Heart rate (HR) and estimated RPE were collected the last 10 s of every min using the Omni RPE (1-10) scale. Criteria for achievement of max effort required that a participant meet a minimum of two of the following: RER value > 1.1, VO_2 plateau with increased workload, RPE 9 -10 (1).

Participants reported to an outdoor asphalt track with instructions to arrive well-rested (no heavy exertion for minimum 24 h) and well hydrated and immediately donned a Polar HR monitor (Polar Electro Oy, Kempele, Finland). Prior to testing (1 h before), participants ingested 500 mL of water along with capsules containing either caffeine ($\sim 6 \text{ mg} \cdot \text{kg}^{-1}$) (CAF), or placebo (PLA) (maltodextrin) matched for appearance and taste. CAF and PLA were randomly assigned, counterbalanced and administered in a double-blind manner. Protocol for CAF and PLA began with a 5 min self-selected warm up on the track (< 0.8 km (0.5 m) at a light pace). Following warm-up, participants ran 2.4 km (1.5 m) at a prescribed RPE4 and then 2.4 km (1.5 m) at a prescribed RPE7. Production bouts (RPE4 and RPE7) were separated by 10 min passive recovery. Duration to the nearest second was recorded for each quarter mile completed with a stop-watch. Throughout production trials, individuals were instructed to adjust velocity as needed to maintain feelings of exertion corresponding to the prescribed RPE. A copy of the Omni RPE scale was placed at the starting position on the track in view of participants as they passed (once per lap). Participants were not allowed to wear a watch and were not made aware of lap times during trials. After the recovery period, and 10 min following the final production bout, participants estimated a Session RPE, reflecting feelings of difficulty for the entire exercise session (12). In addition to VEL, mean HR was recorded per quarter mile lap using the Polar Team II system. To assess environmental conditions between trials, WBGT was calculated [$\text{WBGT} = 0.7 (\text{wet bulb}) + 0.2 (\text{globe}) + 0.1 (\text{dry bulb})$] and recorded to the nearest tenth of a degree (TH-8, Physitemp Instrument Inc., Clifton, NJ).

Statistical Analysis

Using SPSS (v23) Separate 2 (trial) x 6 (time point) repeated measures ANOVA's were used to compare CAF and PLA for dependent measures (HR, VEL). Results were considered significant at $p < 0.05$. S-RPE between trials were compared using a paired T-test for RPE4 and RPE7. Mean WBGT between trials compared using a paired t-test.

RESULTS

Descriptive characteristics of participants were; age (27.1 ± 6.8 years), height (178.8 ± 6.2 cm) mass (72.1 ± 6.8 kg), body fat ($10.9 \pm 4.9\%$), $\text{VO}_{2\text{max}}$ ($60.8 \pm 3.9 \text{ ml} \cdot \text{kg} \cdot \text{min}^{-1}$), and HR_{max} (194 ± 8 bpm). There was no main effect for trial (CAF vs. PLA) for velocity for RPE4 ($p = 0.29$) (Figure 1) or RPE7 ($p = 0.30$) (Figure 2). Similarly, no main effect was found for trial (CAF vs. PLA) for HR for RPE4 ($p = 0.69$) or RPE7 ($p = 0.31$). T-test showed no significant difference ($p = 0.32$) for temperature between CAF (Wet: 11.2 ± 4.4 ; Globe: 14.5 ± 8.7 ; Dry: 12.3 ± 6.5) and PLA (Wet: 13.6 ± 4.5 ; Globe: 16.3 ± 7.1 ; Dry: 14.3 ± 5.6). No significant difference was found for

S-RPE for RPE4 between trials (CAF: 4.0 ± 0.00 , PLA: 4.20 ± 0.42) ($p = 0.17$), however, significance was found for RPE7 between trials (CAF: 7.10 ± 0.32 , PLA: 7.50 ± 0.53) ($p = 0.04$).

DISCUSSION

Previous research indicates caffeine attenuates estimated RPE during exercise at a given workload (3, 9, 18, 21). Killen et al. (21) also showed caffeine significantly reduced Session RPE. Cole et al. (6) and Langford (22) tested caffeine's potential effect on workload selection using the RPE production paradigm during cycling. Because caffeine's effect on RPE production during running is not well-understood, this study examined the effects of $6 \text{ mg} \cdot \text{kg}^{-1}$ caffeine (vs. placebo) on velocity selection and corresponding HR response during outdoor running.

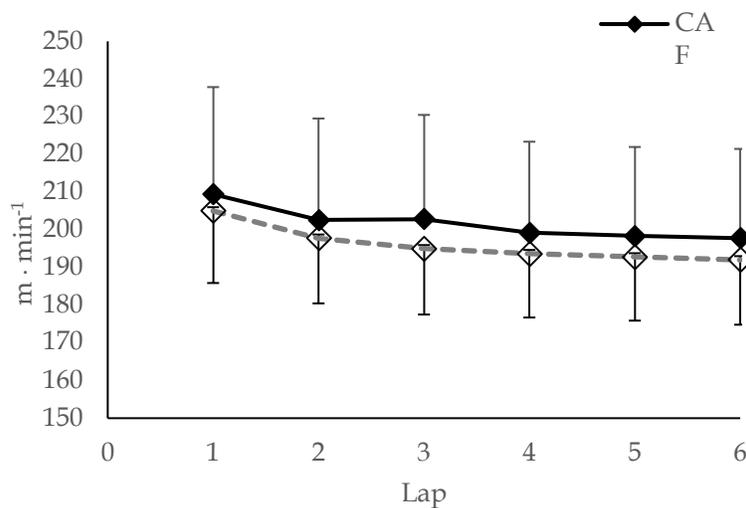


Figure 1. Mean velocity, CAF vs. PLA for RPE4.

Current results show no significant difference for mean velocity following caffeine ingestion. This observation was consistent for an intensity linked with RPE4 (Figure 1) and an intensity linked with RPE7 (Figure 2). Likewise, there were no significant differences for mean HR response (per lap) between CAF and PLA (Figures 3 and 4). Cole et al. (6) found increased total work across three RPE production trials following caffeine (vs. placebo) ingestion (CAF: $277.8 \pm 26.1 \text{ kJ}$, PLA: $246.7 \pm 21.5 \text{ kJ}$). Langford et al. (22) found significantly greater power output selection for a lower intensity trial (prescribed RPE4) (CAF: 127 ± 22 , PLA: $109 \pm 25 \text{ W}$) and a higher intensity (prescribed RPE7) (CAF: 161 ± 36 , PLA: $139 \pm 40 \text{ W}$). Significantly greater values at each time point were also evident. For these studies, when RPE was clamped replicating prescribed perceptual value, CAF ingestion resulted in selection of a greater power output. Cole et al. (6) also attributed higher power selection with CAF to a decreased perception of effort. It is plausible that due to analgesic effects of caffeine, a higher workload is required to elicit a given RPE when participants are under influence of caffeine. This is contrary to conclusions based on mean results in the current study and reasons for discrepancies with Cole et al. (6) and Langford et al. (22) are difficult to discern. Intermodal (cycling vs. running) differences in muscle involvement may partially explain discordance. For example, running is weight-bearing exercise, whereas cycling is not. Because altered pain perception is among the mechanisms by

caffeine is proposed to be ergogenic, it is plausible that in exercise paradigms having greater localized feelings of discomfort and fatigue (factors mediating RPE), caffeine may have a greater potential to enhance performance. Although direct evidence is lacking in the current study, it is arguable that, cycling involves comparatively greater localized feelings of discomfort vs. running, making the potential benefits of caffeine more obvious during cycling when the RPE production paradigm is used. Future investigations using RPE production allowing comparisons among multiple modes involving incrementally altered volumes of active muscle mass could shed light in this regard.

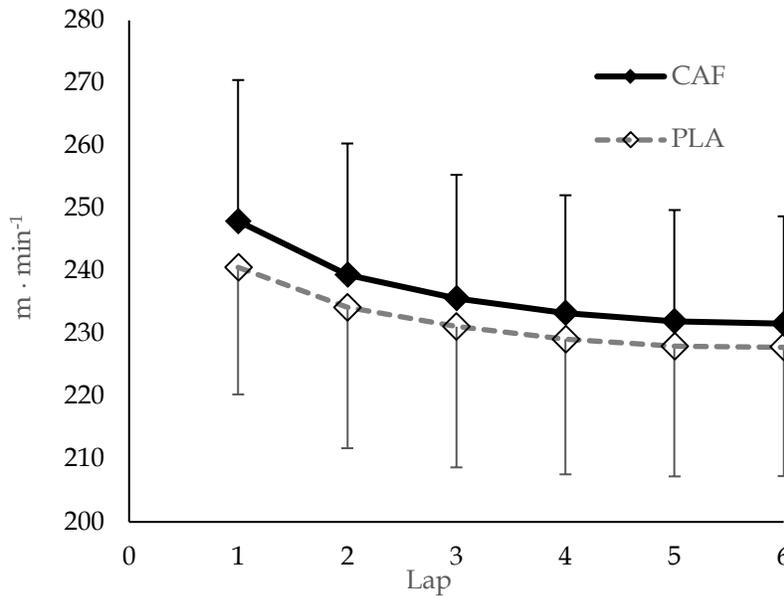


Figure 2. Mean velocity, CAF vs. PLA for RPE7

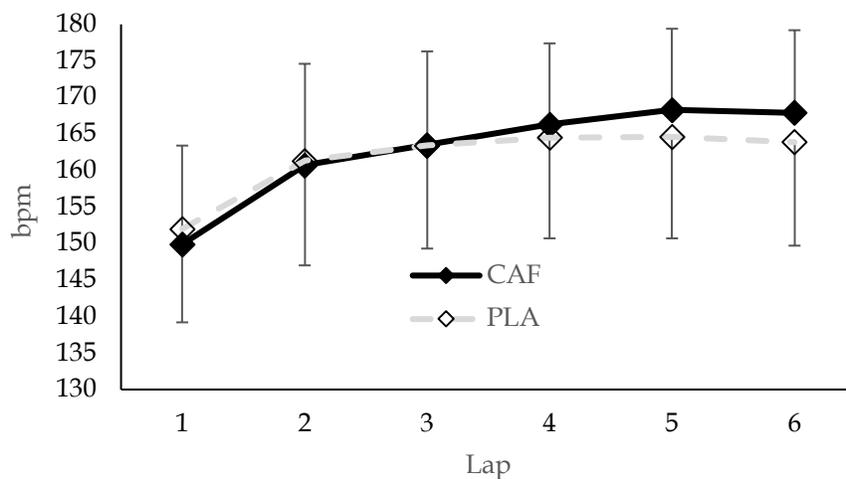


Figure 3. Mean heart rate, CAF vs. PLA for RPE4.

Failure to observe outcomes in the current study for a lower intensity (RPE4) is similar to that of Langford et al. (22). Although significant differences were found in power selection, Langford et al. (22) found no statistical difference in metabolic variables (VO₂, HR, and VE) at a lower prescribed intensity (RPE4) between CAF and PLA trials. With the ergogenic benefit from caffeine linked with augmented pain, it is reasonable that lower intensity exercise below some yet unidentified threshold is a paradigm in which caffeine is unlikely to alter performance or perceptual responses because of a relatively low volume of pain and discomfort. In other words, if there is little exercise-associated pain or discomfort, then there is nothing for caffeine to mitigate. Using Borg's 15-point category scale, Green et al. (17) observed greater production accuracy (based on HR response) at a higher intensity (prescribed RPE 16) vs. lower (prescribed RPE 12) for front crawl swimming. Production trials were completed after overall RPE was anchored and estimated during cycle ergometry. It is well accepted that multiple factors mediate perceived exertion and dominate factors may vary across different exercise paradigms (16). For example, Robertson et al. (25) showed during low intensities, signals accompanying ventilation do not appear to influence perceived exertion but become more dominant with increasing intensity. It would be reasonable then to expect an effect of caffeine to be most probably during RPE7 (than RPE4) due to presence of greater feedback for perceptually based intensity regulation. However, in the current study, mean changes at RPE4 and RPE7 were similar suggesting that factors mediating RPE in a production paradigm may differ (vs. estimation paradigm). More work is needed to fully understand this.

Research suggests CAF blunts estimated RPE (2,7,9,15) and mitigates RPE at a given workload (3, 9, 21). An effect is also present if RPE estimations are similar between trials but a greater volume of work is performed following caffeine ingestion (8). With consistently higher mean VEL for CAF there would be a duration where total work was significantly greater for CAF. Comparable to the results from RPE4, at RPE7 trial means showed no statistical significance for VEL (Figure 2) or HR (Figure 4). However, as seen in Figures 1 and 2 for each lap, selection of velocity was consistently higher after CAF ingestion vs. PLA. It is possible that with longer distance production bouts differences may have evolved owing to the drift in physiological variables such as HR and core temperature frequently observed with extended duration exercise. In Figure 4 a divergence in HR response can be observed with a higher value for CAF. As the discomfort associated with longer exercise bouts grows there is a concomitant increase in potential for caffeine to mitigate these feelings and a higher velocity might be maintained. Direct evidence in the current study is lacking however, future studies should involve production trials which more closely mimic longer training/racing bout distances.

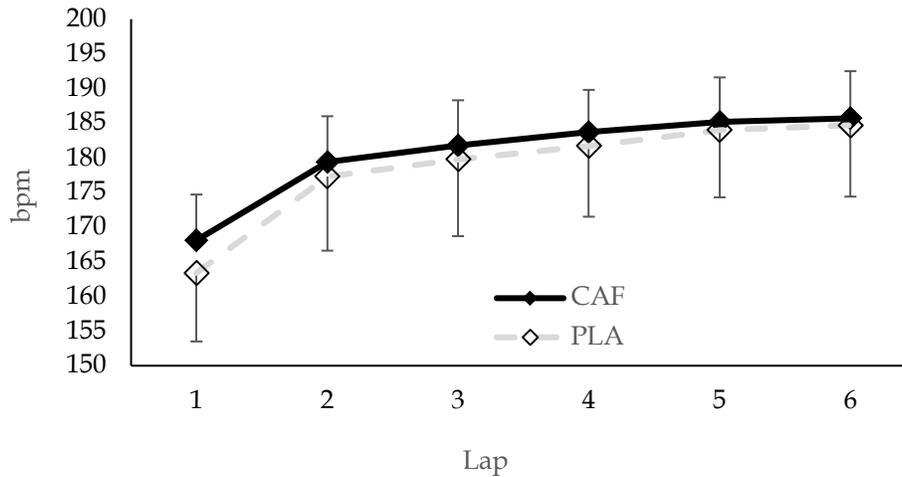


Figure 4. Mean heart rate, CAF vs. PLA for RPE7.

Although no significant differences were found between CAF and PLA for mean responses, it would be premature to definitively conclude caffeine had no effect. Allowing aggregate data analyses to fully dictate conclusions can be misleading particularly when individual responses are evaluated independently. If subsets of the sample perform worse following treatment while some perform better and others truly show no meaningful difference, in that paradigm mean values between trials will be similar and corresponding p values will show no significant differences, yet concluding the treatment had no effect is incorrect. Consequently, it is important to examine individual responses to fully elucidate the possibility of an ergogenic benefit. In the current study, a practical difference in VEL was considered to be a difference of ≥ 12 sec per mile (18 sec per 2.4 km (1.5 m)). Using this criteria, participants were labeled as positive responders (performance improved), negative responders (performance was impaired) or if differences in CAF and PLA trials failed to meet this criteria these participants were labeled non-responders. Individual responses (Table 1) were examined for 20 observations (10 for RPE4 and 10 for RPE7). Using this approach, 9 of 20 trials resulted in a positive response (5 for RPE4, 4 for RPE7). Five trials of 20 were negative responses and six were non-responses. Seven of the 10 participants responded similarly ('positive', 'negative', 'non') for both RPE4 and RPE7 with three being positive responders at both intensities. Therefore, to exclusively conclude that caffeine had no effect on running velocity, would be false in 45% of the observations. Improvement using this criteria, ranged from 26-104 s faster overall with a mean improvement of 54 s. For negative responders, mean time ranged from 26 to 56 s slower with a mean difference of 36 s. In determining the potential for caffeine to influence performance (good or bad), aggregate analyses in the current study provides incorrect information in 14 of 20 observations (9 positive responses, 5 negative responses) and accurate conclusions for only 6 of the 20 observations. Examining individual responses may be uncommon. Yet, to fully explain the effects of caffeine, or other ergogenic aids in which there is a high likelihood of inter-individual variation in responses, we propose it is necessary to carry data analysis beyond assessment of means using standard statistical approaches. Further, identifying factors linked with divergent responses may provide a fruitful area of future inquiry.

Table 1. Individual responses at RPE4 and RPE7 with identification of positive responders (ran faster with CAF), negative responders (ran slower with CAF) and non-responders (no meaningful difference between CAF and PLA).

Participant	RPE4	Response	RPE7	Response
1	-46	Pos	-28	Pos
2	-52	Pos	-12	Non
3	+17	Non	+2	Non
4	-104	Pos	-26	Pos
5	+56	Neg	-86	Pos
6	-12	Non	+10	Non
7	-61	Pos	+1	Non
8	+26	Neg	+33	Neg
9	-39	Pos	-42	Pos
10	+40	Neg	+27	Neg

- Δ sec = faster time on CAF vs. PLA (≥ 18 sec on a 2.4 km (1.5 m)). Table displays difference in trial time in seconds (CAF - PLA).

Killen et al. (21) was the first to show that CAF attenuates S-RPE. In that study, SRPE was assessed following two 30 min cycling bouts in which work volume was equated following double blind administration of caffeine (6 mg · kg⁻¹) vs a matched placebo. A significantly lower session RPE followed caffeine ingestion (6.1 ± 2.2) vs placebo (6.8 ± 2.1). In the current study, results indicate no significant difference for S-RPE for RPE4. However, S-RPE was significantly higher for RPE7 for CAF even with a clamped acute RPE (due to the production paradigm) and equated distance. This difference is meaningful because individuals performed the same amount of work, yet their perception of the overall difficulty of the entire bout was lower for CAF (vs. PLA). Therefore, work production seemed easier with CAF even when the same perceptually-based intensity was prescribed. Akin to acute RPE estimations which are mediated by multiple factors, Session RPE is also proposed to be linked with a myriad of factors and no single mediator (18). From current results, caffeine-mediated alteration in SRPE may be more pronounced or limited to higher intensity paradigms. More work is warranted to more definitely answer this question.

Current results indicate 6 mg · kg⁻¹ CAF body mass did not significantly alter mean values for selection of velocity or corresponding HR responses for running intensity prescribed using RRE. This observation was consistent with lower (RPE4) and higher (RPE7) intensities. While no overall differences were found, individual responses indicate caffeine did have a meaningful effect in selected participants. Results add to the knowledge regarding the influence of caffeine on perceptual responses to exercise in a novel, ecologically valid paradigm. Future research should focus on the variation of CAF response among individuals and seek to further clarify reasons for differing responses among various exercise modes.

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