The Effects of an Acute Dose of *Rhodiola rosea* on Endurance Exercise Performance

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Abstract

Noreen, EE, Buckley, JG, Lewis, SL, Brandauer, J, and Stuempfle, KJ. The effects of an acute dose of *Rhodiola rosea* on endurance exercise performance. *J Strength Cond Res* 27(3): 839–847, 2013—The purpose of this study was to determine the effects of an acute oral dose of 3 $mg \cdot kg^{-1}$ of *Rhodiola rosea* on endurance exercise performance, perceived exertion, mood, and cognitive function. Subjects ($n = 18$) ingested either *R. rosea* or a carbohydrate placebo 1 hour before testing in a double-blind, random crossover manner. Exercise testing consisted of a standardized 10-minute warm-up followed by a 6-mile time trial (TT) on a bicycle ergometer. Rating of perceived exertion (RPE) was measured every 5 minutes during the TT using a 10-point Borg scale. Blood lactate concentration, salivary cortisol, and salivary alpha amylase were measured before warm-up, 2 minutes after warm-up, and 2 minutes after TT ($n = 15$). A Profile of Mood States questionnaire and a Stroop Color Test were completed before warm-up and after TT. Testing was repeated 2–7 days later with the other condition. *Rhodiola rosea* ingestion significantly decreased heart rate during the standardized warm-up (*R. rosea* = 136 ± 17 $b \cdot min^{-1}$; placebo = 140 ± 17 $b \cdot min^{-1}$; mean ± *SD*; $p = 0.001$). Subjects completed the TT significantly faster after *R. rosea* ingestion (*R. rosea* = 25.4 ± 2.7 minutes; placebo = 25.8 ± 3.0 minutes; $p = 0.037$). The mean RPE was lower in the *R. rosea* trial (*R. rosea* = 6.0 ± 0.9; placebo = 6.6 ± 1.0; $p = 0.04$). This difference was even more pronounced when a ratio of the RPE relative to the workload was calculated (*R. rosea* = 0.048 ± 0.01; placebo = 0.057 ± 0.02; $p = 0.007$). No other statistically significant differences were observed. Acute *R. rosea* ingestion decreases heart rate response to submaximal exercise and appears to improve endurance exercise performance by decreasing the perception of effort.

Key Words time trial, ergogenic aid, mood, perception of effort

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Introduction

Rhodiola rosea is an herb that grows in mountainous regions of North America, Europe, and Asia and has been used in traditional folk medicine for centuries as a treatment for fatigue and mood disorders (36). *Rhodiola rosea* was studied extensively in the past by scientists in the former Soviet Union, with majority of these studies showing favorable effects (5). However, limited translation of these studies and questionable experimental control limit their usefulness (36). Several recent studies have supported the results of these early studies. For example, *R. rosea* has been shown to possess both antioxidant and anti-inflammatory properties (2,32), improve cognitive function and reduce mental fatigue (9,31), and reduce biological markers of physiological and psychological stress (9,20).

Although *R. rosea* traditionally has been used to combat physical fatigue, the effect of *R. rosea* ingestion on exercise performance is unclear. *Rhodiola rosea* ingestion increased swim time to exhaustion in rats (1,17), but several studies in humans have failed to observe an effect on exercise performance when it was supplemented alone (32,35) or in combination with other herbs (7,11). However, differences between exercise protocols and doses of *R. rosea* used in these studies limit direct comparisons among them.

A recent study by De Bock et al. (10) found that an acute dose of *R. rosea* increased time to exhaustion during an incremental bicycle ergometer test. However, this same study did not find a significant effect after 4 weeks of supplementation. This is an interesting observation because the traditional use of *R. rosea*, and the bulk of the previous research, has used a model of chronic supplementation of *R. rosea* ranging from several days to several months (5). Nevertheless, other studies have shown a positive effect of an acute dose of *R. rosea* on cognitive performance in humans (31) and exercise performance in rats (29).

The majority of studies that have examined the influence of *R. rosea* supplementation on exercise performance, both in humans and rodents, have used a test that measures time to exhaustion. Although this is a common measurement of endurance performance in the laboratory, some have questioned the validity of this type of a test because it does not mimic the effort of most athletic events that require an athlete to complete a given distance in as little time as possible (8).

Therefore, the purpose of this study was to determine the effects of an acute dose of *R. rosea* on an exercise test that more closely resembles typical endurance competitions (time to complete a given distance rather than time to exhaustion). It was hypothesized that *R. rosea* ingestion would improve exercise performance and cognitive function. It was also hypothesized that *R. rosea* ingestion would decrease the hypothalamic-pituitary-adrenal system's response to the stress of the exercise test.

Methods

Experimental Approach to the Problem

All subjects completed a familiarization trial before any testing. After a 10-minute warm-up at a self-selected pace, the subjects completed a simulated 6-mile time trial on a variable grade course using the Velotron electronic bicycle ergometer (see below for details).

Subjects then returned to the laboratory 2–7 days after the familiarization trial for testing. Subjects ingested either 3 $mg \cdot kg^{-1}$ of *R. rosea* or a carbohydrate placebo, 1 hour before testing in a random, double-blind crossover manner. Upon arrival at the laboratory, a saliva sample was obtained via passive drool and frozen for later analysis of concentration of cortisol and alpha amylase concentration (see below). A capillary blood sample was taken via finger stick and analyzed in duplicate for lactate concentrations using an YSI 2300 Stat Glucose and Lactate Analyzer (YSI, Yellow Springs, OH, USA). Subjects then completed a Profile of Mood States (POMS) questionnaire. The POMS is a 65 question mood survey that evaluates tension/anxiety, depression/dejection, anger/hostility, vigor/activity, fatigue/inertia, and confusion/bewilderment domains through a series of questions rated on a five point scale (21). After this, the subjects then completed a Stroop incongruent word color test in which they were required to read as quickly as they could a list of 100 congruent color words followed by another 100 incongruent words as quickly as they could (18). The subject's score for each condition was the time required to read the list. The subjects then completed a 10-minute warm-up using the Velotron bicycle ergometer placed in ergometer mode. In this setup, a constant workload is placed on the rear wheel that is independent of gearing or cadence. For the warm-up, the subjects pedaled at a self-selected cadence against a resistance that represented 80% of the average watts produced during the familiarization time trial. Two minutes after the completion of the warm-up, a second blood sample was obtained and analyzed for lactate content and a second saliva sample was obtained and frozen for later analysis. Subjects then rode the same simulated 6-mile time trial, which they rode in the familiarization trial. Every 5 minutes during the trial, subjects rated their perceived exertion using a 10-point Borg scale. Two minutes after the completion of the time trial, a third blood sample was taken and analyzed for lactate concentration and a third saliva sample was obtained and frozen for later analysis. Subjects then repeated the POMS questionnaire and the Stroop incongruent word color test.

Subjects returned to the laboratory 2–7 days later to repeat the testing with the other condition. Each subject completed all 3 trials at the same time of day. The trial order was counter balanced, with 9 subjects starting with the *R. rosea* trial first and 9 subjects starting with the placebo. The trial order of the first subject was determined by a coin toss. All subsequent subjects alternated trial order. All trials were performed with an ambient lab temperature of 20–23° C with an electric fan directed on the subjects to minimize heat stress. Water was available ad libitum to the subjects during all trials.

Subjects

Approval for this study was obtained from the Institutional Review Board at Gettysburg College, and written informed consent was obtained from all subjects before any testing. Eighteen recreationally active college women were used as subjects for this study (22 6 3.3 years, 56.6 6 6.2 kg; mean 6 SD). Subjects were recruited from the indoor cycling spinning classes on campus. All subjects were recreationally active but were not systematically training for competition in cycling or another endurance sport or members of a collegiate athletic team. Subjects were required to refrain from caffeine and alcohol consumption and strenuous exercise for 24 hours before all testing. Subjects kept a diet log for a period of 24 hours before the familiarization trial and used this log as a menu for the days before all subsequent testing.

Velotron Setup and Time Trial Procedure

A fully adjustable Velotron bicycle ergometer (Velotron Dynafit Pro; Racermate, Inc., Seattle, WA, USA) was connected to a laptop computer interfaced with a projector that displayed the computer-generated image on a wall in front of the subjects. Before the familiarization trial, the Velotron was adjusted to each subject's specifications (seat height, handlebar height, crank length, etc.), and these settings were used for each subsequent test. The subject was fitted with a chest strap (Polar, Kempele, Finland) for remote monitoring of heart rate. The signal from the chest strap was read by the Velotron controller unit and recorded and displayed in real time by the software. For each time trial, the Velotron was used with the interactive three-dimensional (3D) software version 1.0 (Racermate, Seattle, WA, USA) to mimic an outdoor time trial. This software package essentially presents the subjects with a computer game in which there is a character whose speed is controlled by the subject's efforts on the bicycle and a virtual opponent that is either a recording of a past performance or set to mimic the subject's speed. In addition to the computer characters and race course, this program also displays current gear, current and average speed, distance traveled, subject position relative to the computer-generated opponent, current and average work output in watts, current heart rate, and current revolutions per minute (rpm). These data were calculated using mathematical models included in the 3D

Table 1. Performance during the time trial and warm-up, and the likelihood that the differences between treatments are substantial (greater than the smallest worthwhile change*).

	Rhodiola	Placebo	*t*-Test (*p*)	Likelihood of substantial effect
Time to completion (min)	25.4 ± 2.7	25.8 ± 3.0	0.037	Likely
Average power (W)	130 ± 27	127 ± 28	0.14	Likely
Average heart rate ($b \cdot min^{-1}$)	171 ± 13	171 ± 13	0.45	Almost certainly not
Average cadence (rpm)	79 ± 10	77 ± 8	0.28	Unclear
Average heart rate during the warm-up ($b \cdot min^{-1}$)	136 ± 17	140 ± 17	0.001	Very likely

*1% for time to completion and average power, 0.20 standardized units (change in mean divided by the between subjects *SD*) for average heart rate and average cadence. Data are mean values ± *SD*.

software package. The models take into account variables such as the cyclist's mass and the percent grade of the course to determine the speed of the computer-generated cyclist based on how many watts the subject is able to generate. A 6-mile course with a variable gradient was chosen for this test. Although outdoor courses can have any potential course profile, this course was chosen because it represents a middle ground between a completely flat course and a very hilly course. This course was designed with the same 2-mile profile repeated 3 times. Each 2-mile section had 3 hills. The first hill came at 0.5 miles into the course and had a 0.5-mile section with a gradient of 1% followed immediately by 600-foot section with a gradient of 3%. A 600-foot downhill section with a −3% gradient immediately followed. The second hill was placed at 1.35 miles into the course, and it was 1200 feet in length with a 4% gradient followed immediately by a 600-foot downhill section with a −3% gradient. The final hill was placed at 1.78 miles into the course, and it was 1200 feet in length with a 5% gradient. Subjects were instructed to complete the time trial as quickly as possible, but no verbal encouragement was given during the test. In an attempt to motivate the subjects to put forth a true maximal effort, a virtual opponent was used for all trials. For the familiarization trial, the virtual opponent was set using a 2-second delay. This meant that the computer-generated opponent based its speed on how fast the subject was going but did not respond immediately to changes in the subject's speed. Subjects, however, were not told that the opponent was based on their performance but rather were lead to believe that the opponent was chosen based on their individual abilities and were encouraged to try and put as much distance between themselves and the opponent as possible. Trials 2 and 3 were identical to the familiarization trial, with the exception that the performance from the familiarization trial was used as the virtual opponent for the second trial, and the best performance of either trial 1 or 2 was used as the virtual opponent for the third trial. Previous work (24) has shown that time trials performed in this manner yield good test-retest reliability [coefficient of variation (CV) = 1.4%; intraclass correlation coefficient (ICC) = 0.987; *SEM* = 2.9 seconds]. Additionally, using the software to motivate subjects in this manner has been shown

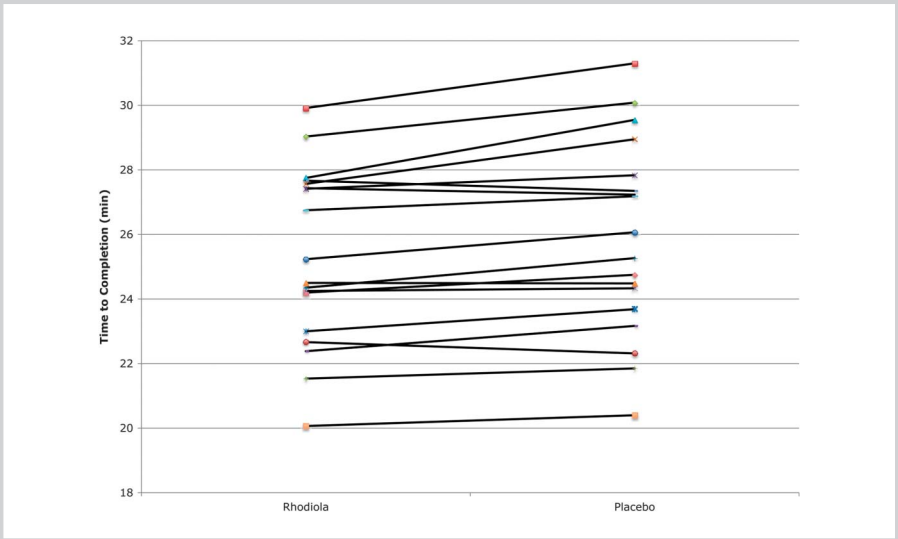

Figure 1. Individual differences in time to complete the time trial between the *Rhodiola rosea* and the placebo treatments.

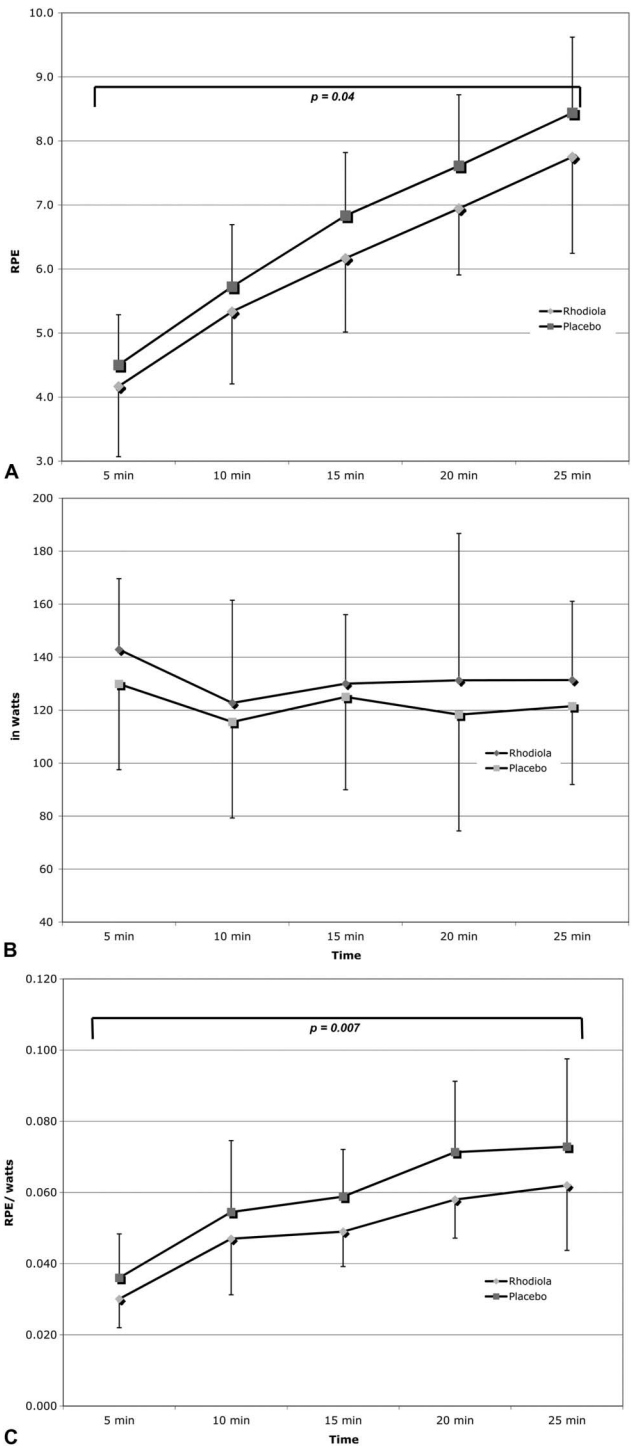

Figure 2. A) The Rating of Perceived Exertion (RPE) during the time trial (mean ± *SD*). The mean rating of RPE during the time trial was significantly ($p = 0.04$) lower following *Rhodiola rosea* treatment. This is likely a substantial effect. B) The workload (in watts) at the time points used to assess RPE during the time trial (mean ± *SD*). There were no significant differences between the treatments; however, using 1% as the minimum worthwhile effect for cyclists, the difference in the mean workload is likely a substantial effect. C) The RPE/watts during the time trial (mean ± *SD*). The mean rating of RPE/watts during the time trial was significantly ($p = 0.007$) lower after *R. rosea* treatment. This is very likely a substantial effect.

to be sensitive enough to detect acute changes in exercise performance as a result of nutritional manipulations (4).

In an effort to further motivate the subjects, the time to complete each trial, average watts, and total cumulative time for all 3 trials were placed on a large white board in the laboratory for each subject to see, and a small prize was awarded to the subject who had the lowest total cumulative time for all 3 trials. This created a very competitive environment among the subjects and kept motivation and interest high throughout the study.

Salivary Analysis

Subjects were not allowed to eat or drink anything other than water starting 1 hour before all testing. Subjects rinsed their mouth with water before all saliva collections to minimize contamination of the samples. Saliva was collected from 15 subjects in polypropylene vials via passive drool through a short straw and stored at −80 °C until analysis. Before analysis, samples were thawed and centrifuged at 10,000*g* for 20 minutes to remove mucins and analyzed in duplicate for cortisol and alpha amylase concentrations using commercially available enzyme immunoassay kits following the manufacturer's recommended methodology (Salimetrics, State University, State College, PA, USA). The intraassay CV was 4.8% for the cortisol assay and 1.4% for the alpha amylase assay. Salivary cortisol is a marker of activation of the hypothalamic-pituitary-adrenal system's response to stress (13). Salivary alpha amylase is a marker of activation of the sympathetic nervous

system's response to stress, and several studies have shown that the salivary alpha amylase response pattern after acute physical or psychological stressors correspond to the response patterns of the sympathetic nervous system (22).

Treatment

Rhodiola rosea was in a powdered form and standardized for 3% Rosavin and 1% Salidroside (Bulknutrition.com, Northborough, MA, USA). An amount of *R. rosea* representing 3 $mg \cdot kg^{-1}$ was measured out for each subject and placed in a colored opaque gelatin capsule. This dose was based on the previous work of De Bock et al. (10) who observed an increase in endurance performance after acute ingestion of *R. rosea*. Subjects ingested the capsule on an empty stomach 1 hour before testing.

Maltodextrin (Now Foods, Bloomingdale, IL, USA) was used as a placebo. An amount of 3 $mg \cdot kg^{-1}$ was measured out for each subject and placed in a colored opaque gelatin capsule that was indistinguishable from the *R. rosea* treatment. The amount of total Maltodextrin ingested was approximately 170 mg, and thus it was unlikely that it had any impact on metabolism or exercise performance. Subjects ingested the capsule on an empty stomach 1 hour before testing. An individual not directly involved with the data collection prepared all capsules, and the contents were not revealed until after the study was completed.

Statistical Analyses

All data were analyzed using SPSS version 13 (SPSS, Inc., Chicago, IL, USA). Average heart rate during the standardized warm-up and data from the time trial were analyzed using a 2-tailed dependent *t*-test. Following the advice of others (19), the rating of perceived exertion (RPE) scores during the time trial were averaged and analyzed using a 2-tailed dependent *t*-test. To make sure that any differences in the RPE scores between trials were not the result of different workloads at the time points used, the ratio of the RPE to workload was calculated for each time point, and the average for the entire time trial was analyzed using a 2-tailed dependent *t* test. Salivary hormones, blood lactate, and all cognitive tests were analyzed using a treatment by time repeated-measures analysis of variance (ANOVA) with a Tukey's honestly significant difference post hoc when indicated. The correlation between the change in the RPE and the change in the time to complete the time trial after *R. rosea* treatment was determined using a 2-tailed Pearson's *r*. For all tests, significance was set at $p \leq 0.05$. All values are reported as mean ± *SD*.

The chances that the true effects are substantial were calculated on log-transformed data using a spreadsheet (15), which has been detailed previously (16,28). Briefly, this spreadsheet calculates the chances that the true effects are substantial when the smallest worthwhile effect is entered in (3). For the time trial performance data, we used 1% as the smallest worthwhile effect because this has been shown to be the smallest worthwhile change for cyclists competing in a time trial (27). It is unclear what the smallest worthwhile effect would be for the other variables, so we chose a smallest worthwhile change of 0.20 standardized units, which is the change in mean divided by the between subjects *SD* (6). A qualitative assessment of the chance of a substantial effect is listed when the chances of benefit were greater than 5% and the chances of harm were less than 5%. When the chances of benefit and harm were greater than 5%, the likelihood of a substantial effect was interpreted as unclear. The thresholds used in the spreadsheet for assigning qualitative terms to chances of substantial effects were <0.5%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25–75%, possibly; >75%, likely; >95%, very likely; >99% almost certain.

Table 2. Salivary hormones and blood lactate and the likelihood that the differences between treatments are substantial (greater than the smallest worthwhile change*).

Measurement	Time	*Rhodiola*	Placebo	Likelihood of substantial effect
Lactate ($mmol \cdot L^{-1}$)	Before	1.2 ± 0.3	1.1 ± 0.3	Unclear
	Warm-up	3.4 ± 1.6†	2.9 ± 0.9	Possible
	Time trial	6.8 ± 1.7†‡	6.9 ± 1.6†‡	Unclear
Salivary cortisol ($\mu g \cdot dl^{-1}$)	Before	0.119 ± 0.057	0.140 ± 0.054	Unclear
	Warm up	0.109 ± 0.029†	0.128 ± 0.067†	Unclear
	Time trial	0.214 ± 0.128†‡	0.239 ± 0.168†‡	Unclear
Salivary alpha amylase ($U \cdot ml^{-1}$)	Before	65.0 ± 71.9	76.6 ± 99.1	Unlikely
	Warm up	120.5 ± 132.0†	115.2 ± 113.6†	Unlikely
	Time trial	218.5 ± 235.4†‡	164.7 ± 290.6†‡	Likely

*0.20 standardized units (change in mean divided by the between subjects *SD*). Data are mean values ± *SD*. ANOVA = analysis of variance.
†A treatment by time repeated-measures ANOVA revealed a significant ($p < 0.05$) difference from the"Before" value.
‡A treatment by time repeated-measures ANOVA revealed a significant ($p < 0.05$) difference from the warm-up value.

Table 3. Results of the profile of mood states questionnaire and Stroop color test and the likelihood that the differences between treatments are substantial (greater than the smallest worthwhile change*).

Measurement	Time	*Rhodiola*	Placebo	Likelihood of substantial effect
Fatigue†	Pre	6.8 ± 3.3	7.1 ± 4.0	Unclear
	Post	9.8 ± 4.3	10.7 ± 4.9	Likely
Tension	Pre	10.4 ± 4.4	9.2 ± 4.8	Unclear
	Post	11.1 ± 4.8	8.9 ± 4.8	Unclear
Confusion†	Pre	7.1 ± 3.5	7.1 ± 4.0	Unclear
	Post	5.3 ± 2.4	6.4 ± 3.8	Unclear
Anger	Pre	5.2 ± 4.4	3.9 ± 2.7	Unclear
	Post	5.6 ± 5.9	4.7 ± 6.5	Unclear
Vigor	Pre	14.3 ± 6.7	14.6 ± 5.4	Unclear
	Post	13.3 ± 4.8	13.6 ± 5.6	Unclear
Depression	Pre	4.4 ± 5.3	4.1 ± 4.7	Unclear
	Post	6.1 ± 5.7	4.7 ± 5.7	Unclear
Stroop test Congruent (s)	Pre	37.9 ± 4.7	38.7 ± 4.5	Possibly
	Post	37.2 ± 5.6	38.4 ± 4.8	Unlikely
Stroop test Incongruent (s)†	Pre	74.3 ± 7.1	76.9 ± 11.0	Unclear
	Post	68.8 ± 6.9	70.2 ± 10.0	Possibly

*0.20 standardized units (change in mean divided by the between subjects *SD*). Data are mean values ± *SD*.

†A treatment by time repeated-measures analysis of variance revealed a significant ($p < 0.05$) main effect for time.

Results

Average heart rate during the standardized warm-up (Table 1) was significantly lower for the *R. rosea* treatment (*R. rosea* = 136 ± 17 b·min^{-1}; placebo = 140 ± 17 b·min^{-1}; $p = 0.001$), and this is very likely a substantial effect. Time to completion during the time trial (Figure 1 and Table 1) was significantly lower for the *R. rosea* treatment (*R. rosea* = 25.4 ± 2.7 minutes; placebo = 25.8 ± 3.0 minute; $p = 0.037$), and this is likely a substantial effect. No significant differences were observed between treatments for average power (*R. rosea* = 130 ± 27 W; placebo = 127 ± 28 W; $p = 0.14$), average heart rate (*R. rosea* = 171 ± 13 b·min^{-1}; placebo = 171 ± 13 b·min^{-1}; $p = 0.45$), or average cadence (*R. rosea* = 79 ± 10 rpm; placebo = 77 ± 8 rpm; $p = 0.28$) during the time trial (Table 1). However, the difference between treatments for average power is likely a substantial effect (Table 1).

Rating of Perceived Exertion

Results of the RPE during the time trial are presented in Figure 2A. Subjects had a significantly lower mean RPE during the *R. rosea* treatment (*R. rosea* = 6.0 ± 0.9; placebo = 6.6 ± 1.0; $p = 0.04$), and this difference is likely a substantial effect. Although there were no significant differences between treatments for power output at any time point during the time trial, there was a small absolute increase in workload at all time points after *R. rosea* treatment (Figure 2B). As a result, the difference in perceived exertion between treatments was even more pronounced when expressed as a ratio of the RPE relative to the workload (*R. rosea* = 0.048 ± 0.01; placebo = 0.057 ± 0.02; $p = 0.007$; Figure 2C), and this difference is very likely a substantial effect. For all trials, the RPE was significantly correlated with the time to complete the time trial ($r = 0.774$; $p = 0.001$). The change in the RPE after *R. rosea* treatment was also significantly correlated with the change in the time to complete the time trial after *R. rosea* treatment ($r = 0.550$; $p = 0.018$).

Salivary Hormones and Blood Lactate

The results of the salivary hormone and blood lactate measurements are presented in Table 2. A treatment by time repeated-measures ANOVA revealed no significant differences between treatments, but there was a significant main effect for time for salivary cortisol, salivary alpha amylase, and blood lactate concentrations. However, the higher concentration of salivary alpha amylase in the *R. rosea* treatment after the time trial is likely a substantial effect.

Profile of Mood States and Stroop Color Test

Results of the POMS Questionnaire and the Stroop color test are presented in Table 3. A repeated-measures treatment by time ANOVA revealed a significant main effect for time for the fatigue and confusion domains and the Stroop incongruent word color test. No other significant differences were observed for any of the other domains or for the Stroop color test. However, the lowered rating for the fatigue domain after the time trial in the *R. rosea* treatment is likely a substantial effect.

Discussion

The purpose of this study was to examine the effects of an acute dose of 3 mg·kg^{-1} of *R. rosea* on endurance exercise performance, RPE, mood, cognitive function, and stress hormone production in young active women. The exercise test used in this study was a 6-mile indoor time trial using the Velotron electronic bicycle ergometer. For this test, the

subjects were asked to complete the virtual 6-mile course in as little time as possible. Before the test, the subjects performed a 10-minute warm-up that was standardized to 80% of the average watts they maintained during a familiarization trial of the 6-mile time trial course. During this warm-up, there was a significant reduction in the average heart rate during the *R. rosea* treatment compared with the placebo ($p = 0.001$; Table 1), and this is very likely a substantial effect. A similar effect on submaximal heart rate was observed by De Bock et al. (10) who found that *R. rosea* ingestion significantly lowered heart rate at 6 minutes during an incremental bicycle test to exhaustion. Spasov et al. (33) observed a similar effect using a slightly different methodology. In the Spasov et al. study, heart rate was maintained at 170 $b \cdot min^{-1}$, and the workload the subjects attained was measured. They observed a tendency ($p = 0.10$) for the subjects to be able to sustain a higher workload at a heart rate of 170 $b \cdot min^{-1}$ after 20 days of supplementation of 100 $mg \cdot d^{-1}$ of *R. rosea*. Spasov et al. (33) also found that heart rate recovered significantly faster after exercise in the *R. rosea* group. It is unclear from the present data what caused the reduction in heart rate during the warm-up after *R. rosea* treatment. There were no differences observed between treatments for salivary alpha amylase concentration either before or immediately after the warm-up (Table 2). Because salivary alpha amylase is a marker for sympathetic activation (22), it is unlikely that the lowered heart rate during the warm-up after *R. rosea* supplementation was the result of a reduced sympathetic tone. A more likely candidate is a change in endogenous opioids as a result of *R. rosea* ingestion. Older studies from the former Soviet Union suggest that *R. rosea* increases endogenous opioid production or receptor sensitivity (5), and a recent study has cited an increase in endogenous opioid production as a likely candidate to explain the positive effects of *R. rosea* on exercise performance (10). Although there currently is little data to directly back up the hypothesis that *R. rosea* ingestion can increase endogenous opioids, there is data to support a mechanism by which this is possible. It has been known for sometime that the concentrations of various monoamines in the brain, such as dopamine and serotonin, are increased following ingestion of Rhodiola rosea (5, 26); which is likely a result of Rhodiola rosea induced inhibition of monoamine oxidase, which is the enzyme that degrades biogenic monoamines (34). Because the monoamine dopamine is necessary for production of endogenous opioids in the brain (23), it is tempting to speculate that the increased levels of dopamine seen after *R. rosea* ingestion could also increase endogenous opioid production. If this indeed is the case, it would explain the reduction in heart rate observed during the standardized warm-up in the *R. rosea* trial because opioids have been shown to reduce the effects of beta adrenergic stimulation on cardiac cells (37) and lower heart rate in vivo (12). However, more research is needed to determine if an increased production of endogenous opioids is responsible for the reduced heart rate response observed during submaximal exercise after *R. rosea* ingestion.

An increased production of endogenous opioids after *R. rosea* ingestion is also consistent with the effects observed during the time trial. The mean of the rating of the perceived exertion scores was significantly ($p = 0.04$) lower during the *R. rosea* trial compared to the placebo (Figure 2A), and this change was significantly correlated to the faster time trial times observed during the *R. rosea* trial ($r = 0.550$; $p = 0.018$). This difference was even stronger ($p = 0.007$) when the slightly higher workload maintained during the *R. rosea* trial was taken into account (Figures 2B,C). Although the repeated-measures ANOVA did not find a significant difference between the treatments in the fatigue domain score after the time trial, analysis of the data using the spreadsheet developed by Hopkins (15) indicates that the lower score after *R. rosea* treatment is likely a substantial effect (Table 3). This, combined with the lowered rating of perceived exertion scores observed, strongly suggests that *R. rosea* was able to attenuate the perception of the effort produced in the time trial. Previous research has found that the rating of perceived exertion during exercise is significantly higher when subjects are given the opioid receptor antagonist naloxone and that this results in a significant decrease in exercise performance (14,30). After this line of reasoning, De Bock et al. (10) attributed an observed increase in time to exhaustion after acute ingestion of *R. rosea* to an increase in opioid production. Unfortunately, De Bock et al. did not measure endogenous opioids or RPEs during exercise, which would have strengthened their hypothesis that the results were from an increased endogenous opioid production. Although a change in endogenous opioid production after *R. rosea* ingestion would explain the results of this study, more research is needed to evaluate this hypothesis.

In this study, the subjects completed the time trial significantly faster after ingestion of *R. rosea* ($p = 0.037$; Table 1), which is in agreement with De Bock et al. (10) who observed a significant increase in time to exhaustion during an incremental bicycle test to exhaustion, but it is in disagreement with other studies in humans that have shown no effect of *R. rosea* supplementation on endurance performance (7,11,32,33,35). Although vastly different exercise protocols, subject populations used, and doses of *R. rosea* used limit direct comparisons between the studies, both this study and the study by De Bock et al. (10) were acute studies, and the other studies looked at the effects after several days of supplementation. This brings up the possibility that an acute dose of *R. rosea* can improve endurance exercise performance, but the effects are lost with long-term supplementation. In direct support of this, the De Bock et al. (10) study failed to observe an effect after 4 weeks of supplementation with *R. rosea*. However, the hypothesis that *R. rosea* is only effective acutely fails to explain the observation that chronic supplementation in animals has shown an improvement in endurance exercise performance (1,17). Clearly, more work is needed to determine under what conditions *R. rosea* supplementation is advantageous.

Although it is a popular belief that *R. rosea* can reduce activation of the hypothalamic-pituitary-adrenal axis during periods of stress (5), this study failed to find an effect of *R. rosea* on salivary cortisol, either at rest or after exercise (Table 2). This is in contrast to a study by Olsson et al. (25) that observed a reduction in morning salivary cortisol levels after 28 days of supplementation with *R. rosea* in subjects with stress-related fatigue. It is unclear whether the difference between these 2 studies was a result of Olsson et al. (25) collecting salivary samples immediately after awakening when cortisol levels are normally elevated, the longer supplementation period employed by Olsson et al., or the use of subjects who self reported stress-related fatigue. More work is needed to determine under what circumstances *R. rosea* can influence cortisol levels.

Practical Applications

The results of the present investigation show that acute ingestion of *R. rosea* by recreationally fit women can lower the perception of effort during high-intensity endurance exercise and improve performance when the goal is to complete a given distance as quickly as possible. This has obvious implications for recreational athletes, or "weekend warriors," who may choose to compete in endurance events. However, caution should be used when extrapolating these results to other populations. For example, it is unclear whether similar results would be seen in highly trained endurance athletes who consumed *R. rosea* before races. It is also unclear whether the effects seen from an acute dose would be seen with chronic dosing. Because a previous study has shown a loss of effect with chronic treatment (10), athletes might want to use *R. rosea* sparingly in an attempt to maintain the ergogenic effects. The present investigation also shows that acute ingestion of *R. rosea* can lower the heart rate response to submaximal exercise. Although this effect was very pronounced from a statistical standpoint ($p = 0.001$), the real-world benefits of this to athletes who consume *R. rosea* before competition or training is currently unknown. It is a common popular belief that *R. rosea* can decrease the body's response to stress, and many athletes consume *Rhodiola* in the hopes that it can help them deal with a heavy training schedule and the stress of modern life. Although it cannot be ruled out that chronic supplementation may be beneficial in this respect, this study found no evidence that *R. rosea* can reduce the activation of the hypothalamic-pituitary-adrenal system's after intense exercise.

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