

Deception of Heart Rate is Unable to Improve Functional Threshold Power in Cyclists

Original Research

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Abstract

Introduction: Studies investigating the effects of deception on endurance performance have been somewhat inconclusive. The purpose of this study was to explore the use of biofeedback deception of heart rate (HR) in an attempt to improve athletic performance.

Methods: Thirteen individuals (10 males, 3 females) completed two 20-minute functional threshold power (FTP) cycling tests. In the control (CON) condition, their correct HR was displayed, while in the deception (DEC) condition an incorrect HR was displayed (correct HR – 10 bpm). Paired samples t-tests were used to compare cycling variables such as power output, speed and work between conditions. Actual HR was analyzed using 2 (condition) x 10 (time; every two minutes) repeated-measures ANOVAs.

Results: Mean power output in the CON condition was 226.7 ± 69.3 W and 222.6 ± 65.4 W in the DEC condition ($p > .05$). The total amount of work performed was nearly identical between conditions (CON: $709.2 \pm$ J, DEC: $709.3 \pm$ J; $p > .05$). There were no differences in actual HR between conditions (all $p > .05$).

Conclusions: Biofeedback deception of HR was unable to improve performance. Verbal encouragement may be a moderating variable that allows successful deception to occur. Possible future studies are presented that will allow further testing of this hypothesis.

Key Words: biofeedback, cycling, endurance

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Introduction

It is crucial for exercise/sport scientists and coaches to understand how the brain interacts with and influences athletic performance. Physiological training methods used in endurance sports have been studied very closely and it is well understood that factors such as cardiorespiratory fitness, lactate threshold and economy are important for performance ¹⁻³. However, these variables have limits and once they

are reached athletes often search for alternatives to improve their performances. Psychological methods are increasingly being used in combination with physiological training, such as mental skills exercises, using competitors, imagery and self-talk ^{4,5}. Another method that has shown promise is deception.

In the sport setting, deception involves modifying athletes' expectations prior to or during a performance, and acts to alter their perceptions ⁶. There has been some research recently investigating the effects of deception on sports performance, but studies have been somewhat inconclusive ⁷⁻⁹. This may be due to individual differences between

participants, methodology, or ineffective deception (e.g., the athlete knew about the deception or did not truly believe it). A review on the topic ⁶ indicated that out of 31 studies using deception with endurance athletes, 10 (or 32%) were able to show improvements in performance. An interesting approach of using visual avatars on a computer screen has been used by some research groups, such as Stone et al. ¹⁰. For their study, a 4-km time trial was the performance measure. In the deception condition, they raced against an avatar whose power output was set to 102% of each participant's baseline trial. The researchers found that this small difference led to a significantly faster time trial. Another study ¹¹ using a visual avatar deceived cyclists into believing that they were competing with a simulated competitor with a similar ability level. They were in fact competing against their own best completion time during a 2-km time trial. In the end, the participants finished the time trial against the avatar significantly faster than any other trial.

A variant of deception using the manipulation of physiological measures, rather than performance-related, can be described as biofeedback deception. One promising study utilizing this form of deception was performed by Castle and colleagues ¹². This study used trained cyclists who were asked to perform three cycling time trials; one trial was in temperate conditions (~21°C, 43%RH) and the other two were in hot, humid conditions (~31°C, 60%RH). In one of the hot trials, they were told that it was 5°C lower than it actually was. However, an important aspect within their study was biofeedback deception of the athletes' core temperature. Participants were shown an incorrect (lower) core body temperature, which led to a significantly faster time trial despite the same environmental conditions.

In another study ¹³, participants were also deceived of ambient temperature. Similar to the Castle et al. (2012) study, there was a control (21°C, 43% RH) a hot condition (31°C, 65% RH) and a deception condition at 31°C where they were told that it was 5°C cooler than it actually was. They were asked to run a simulated 5-km race in each of these three conditions. In this study, however, deception did not lead to a significantly faster completion time, and no differences were shown in perception of effort or thermal sensation. Results from these two studies, taken together, suggest that it is likely that biofeedback deception was the key to eliciting performance benefits. Unfortunately, athletes do not have access to core temperature information during an event, which decreases the ecological validity of their results. A more readily available and cost-effective physiological measure is heart rate (HR). To the best of our knowledge, biofeedback deception of HR has not been explored.

The primary purpose of this study was to examine the use of biofeedback deception of HR in an attempt to improve athletic performance. Specifically, the aim was to determine if deception would lead to a mismatch between the expected and actual HR, leading to participants believing that their HR was lower than anticipated at the current intensity, thus resulting in increased power output. We hypothesized that the deception would be successful in improving performance, as shown by a greater average power output during a 20-minute functional threshold power (FTP) cycling test compared to a control condition.

Scientific Methods

This was a cross-sectional, repeated measures study. Participants were asked to come to the lab for three visits. The first visit primarily consisted of the informed consent procedure and a $\text{VO}_{2\text{max}}$ test to assess cardiorespiratory fitness. The remaining sessions were 20-minute FTP cycling trials, with either 1) correct heart rate data (control condition, or CON), or 2) incorrect heart rate data displayed to the participant (deception condition, or DEC). The order of these last two sessions was counterbalanced to reduce any order effect. Participants were under the impression that the final two sessions were identical, and the researchers were testing the validity of new HR equipment. The hypothesis was that deception would lead to improved performance on the FTP test, compared to a control condition, shown by a higher average power output over the course of the test.

Participants

Thirteen individuals volunteered to take part in this study (10 men, 3 women). The mean $\pm$ SD age was 29.4 ± 10.2 years and the body mass index was $23.6 \pm 3.2 \text{ kg} \cdot \text{m}^{-2}$ (body mass $75.0 \pm 12.4 \text{ kg}$, height $178.2 \pm 8.5 \text{ cm}$). Participants were recruited from the student body of the university, as well as local cycling clubs. Inclusion criteria consisted of recent and consistent cycling experience, no lower extremity injuries in the prior six months, and to be classified as low risk according to the risk stratification guidelines ¹⁴ set forth by the American College of Sports Medicine (ACSM). The study was approved by the university's Human Subjects Institutional Review Board (17-03-27). There were three total visits to the laboratory.

Protocol

Session 1: Upon arrival to the laboratory, the participants were read the informed consent form in full. They were also asked to complete the health screening form ¹⁵. If they agreed to and signed the consent, and they were classified as low risk according to the health screening form, they were asked to continue. Their height and mass were then recorded during this session. A familiarization which involved an explanation of the Borg 6-20 rating of perceived exertion (RPE) scale ¹⁶ and the self-paced VO₂max (SPV) test protocol ^{17,18} was performed. They were then asked to practice cycling at various RPE values on the cycling ergometer until they felt comfortable and were fully capable of adjusting workload during exercise. After a sufficient period of rest, the SPV test was administered. During this test they were allowed to constantly regulate their pedal cadence and resistance but were asked to maintain RPE values of 11, 13, 15, 17 and 20 for two minutes each (in this order); the test lasted ten minutes in total. After the test, the participants were allowed to recover as needed. A metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT) was used for the SPV, and was calibrated immediately prior to each test. During each stage, ventilation (VE), heart rate (HR), VO₂ (volume of oxygen consumed) and VCO₂ (volume of carbon dioxide produced) and respiratory exchange ratio (RER) were recorded. The data was collected breath-by-breath, and the maximal value from calculated 15-breath rolling averages was used for descriptive analyses ¹⁹.

Sessions 2 and 3: These testing sessions were identical in procedure to each other except that in one condition their actual HR was displayed (Figure 1), while in another condition their incorrect HR was given. This “incorrect” HR was 10 bpm lower than the actual recorded instantaneous value. In both conditions, they were not forced to look at the HR display; they were simply told that the HR would be available the entire test for them to view and guide their performance. The test condition order was assigned randomly. A 20-minute FTP test was performed, and they were only allowed to see their HR throughout each test; they were blind to all other collected variables. This test was performed after a 15-minute warmup at a moderate intensity. At every other minute (minutes 2, 4, 6, etc.) the actual HR was recorded. Throughout the tests, lower limb muscle activity was recorded via electromyography. Blood lactate concentration was recorded before and after each test.

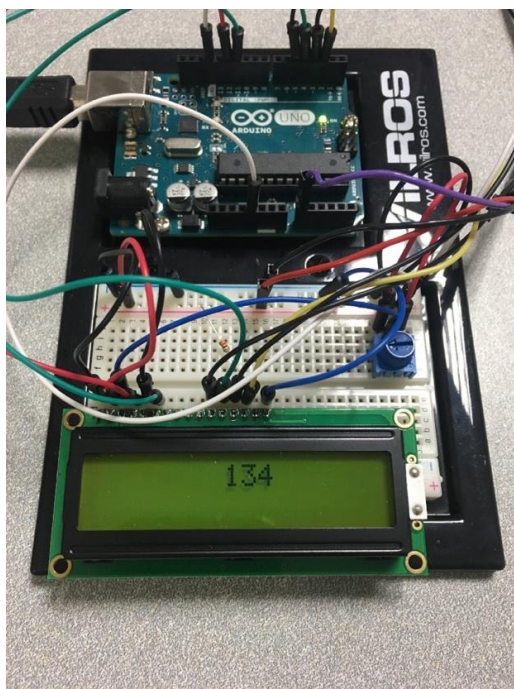


Figure 1 – Arduino Uno unit with HR display

Instrumentation

Cycling variables: All testing was performed on a Wattbike Pro cycle ergometer (Woodway, Waukesha, WI), which records data at a rate of 100Hz and provides output for every pedal stroke. It calculates power output by using a load cell that is located next to the chain of the bike. As the chain runs over this load cell, it calculates the sum of all the forces being applied to the chain through the crank ²⁰. Variables that were recorded included cadence, speed, power,

work, force and torque. Custom MatLab (MathWorks, Natick, MA) code was written to filter the Wattbike cycling data.

Physiological variables: Heart rate was monitored through the use of an optical device that was attached to the participants' earlobe. The signal was wired to a control unit (Arduino Uno, Figure 1), and through software coding was displayed as either the true HR or an incorrect HR (true HR – 10 beats per minute) on an LCD screen that was in full view of the participants. Wireless electromyography (EMG; Noraxon, AZ, USA) was used to monitor myoelectric activity of the working skeletal muscles. Specifically, the activity of the quadriceps was collected with surface skin electrodes placed over the dominant rectus femoris. EMG was continuously recorded throughout each test at a 1500Hz sampling frequency. Raw EMG data were filtered using a band-pass filter of 10-500 Hz. The filtered EMG data were then rectified and smoothed using full wave rectification and root mean square (RMS) methods with 20ms moving window. The smoothed RMS data were normalized to its peak value. The normalized EMG data were averaged over ten 2-min periods. Blood samples for analysis of lactate concentration ([BL]) were collected via a finger prick using a disposable lancet and were measured through use of an Accusport portable lactate analyzer (Sport Resource Group, Hawthorne, NY) immediately before and after each FTP test.

Statistical Analyses

IBM SPSS Statistics version 26.0 was used to analyze all data. *A priori* power calculations were not performed beforehand. Paired samples t-tests were used to compare the cycling variables between the two conditions (CON and DEC). HR and EMG data were analyzed using 2 (condition) x 10 (time; every two minutes) rmANOVAs. [BL] was analyzed with a 2 (condition) x 2 (time: pre/post) repeated-measures Analysis of Variance (rmANOVA). When the assumption of sphericity was violated, Greenhouse-Geisser corrections were used. Significance level was set at *a priori* at $p < .05$. Partial eta squared was provided as an effect size for the ANOVAs, and Cohen's *d* values were provided as an effect size for the t-tests (thresholds: small=0.2, medium=0.5, large=0.8).

Results

The results of the VO₂max testing can be seen in Table 1.

Table 1. VO₂max testing results.

<i>Variable</i>	<i>Mean±SD</i>
Heart rate (bpm)	184.4±11.0
VE (L·min ⁻¹)	150.4±26.9
Absolute VO ₂ (L·min ⁻¹)	4.00±0.89
VCO ₂ (L·min ⁻¹)	4.54±0.96
Relative VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	53.7±9.7
RER	1.18±0.07

Cycling variables:

There was no difference in average power output during the 20-min FTP tests between conditions (CON: 226.7±69.3 W, DEC: 222.6±65.4 W; $p = .589$; $d = .15$). There was also not a significant difference between conditions in mean work ($p = .997$; $d = .01$). There were no differences found for the mean values of cadence, speed, torque and force (all $p > .05$). The values for each variable can be seen in Table 2, and the mean power output is shown in Figure 2.

Physiological variables:

For actual HR, the rmANOVA showed no main effect of condition ($p = .302$) and no interaction effect ($p = .637$). There was a significant main effect of time ($F(1.790, 21.482) = 91.850$, $p < .001$, $\eta_p^2 = .884$) as HR increased throughout both conditions (Figure 3). There was no difference in the actual recorded HR between conditions.

Table 2. Comparison of the average Wattbike cycling variables between conditions.

<i>Variable</i>	<i>CON</i>	<i>DEC</i>	<i>p</i>	<i>Effect size</i>
Cadence (rev·min⁻¹)	97.4±10.3	96.4±11.3	.207	.37
Speed (km·hr⁻¹)	38.3±4.3	38.1±4.1	.572	.35
Power (W)	226.7±69.3	222.6±65.4	.589	.15
Relative Power (W·kg⁻¹)	2.57±1.04	2.62±1.10	.145	.43
Work (J)	709.2±122.0	709.3±120.1	.997	.01
Torque (N·m)	21.9±5.2	21.8±5.0	.899	.04
Force (N)	128.9±30.3	128.5±29.3	.907	.03

Note: Values presented as mean±SD. Effect sizes provided as Cohen's *d* (small: 0.2, medium: 0.5, large: 0.8)

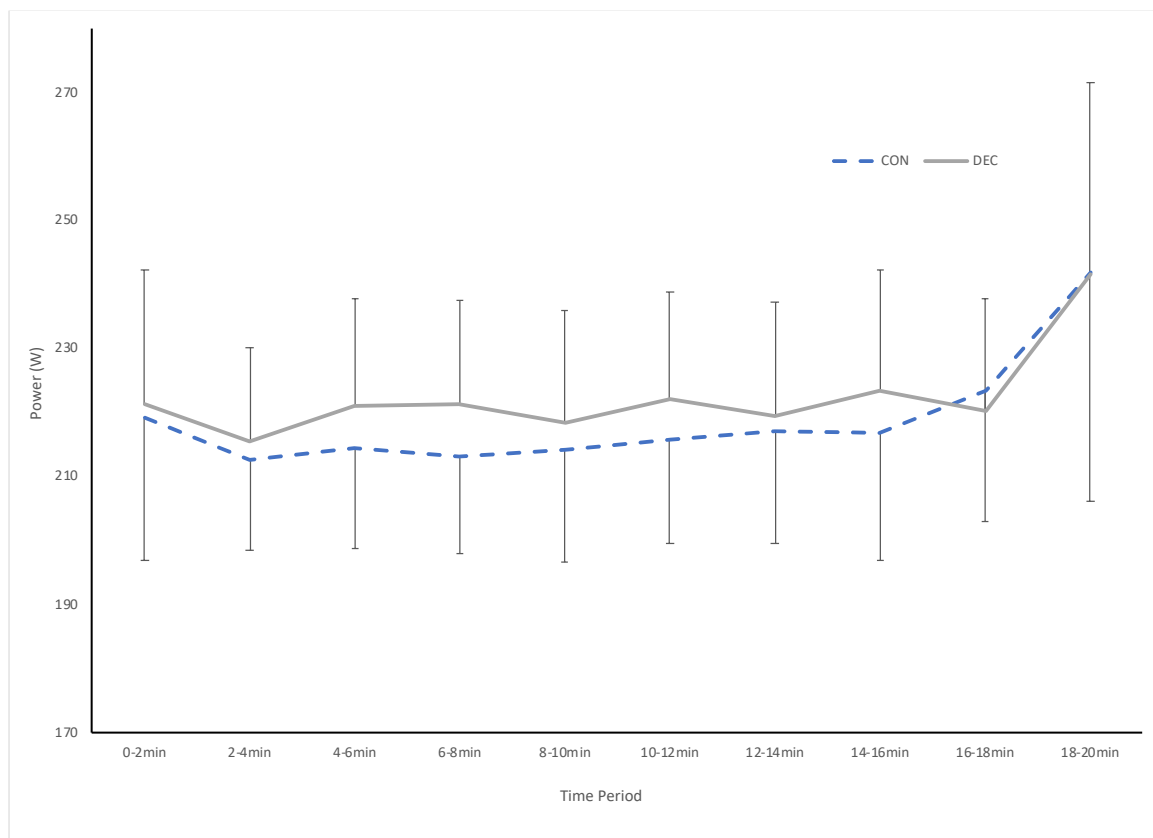


Figure 2. Mean power output for each 2 min period.

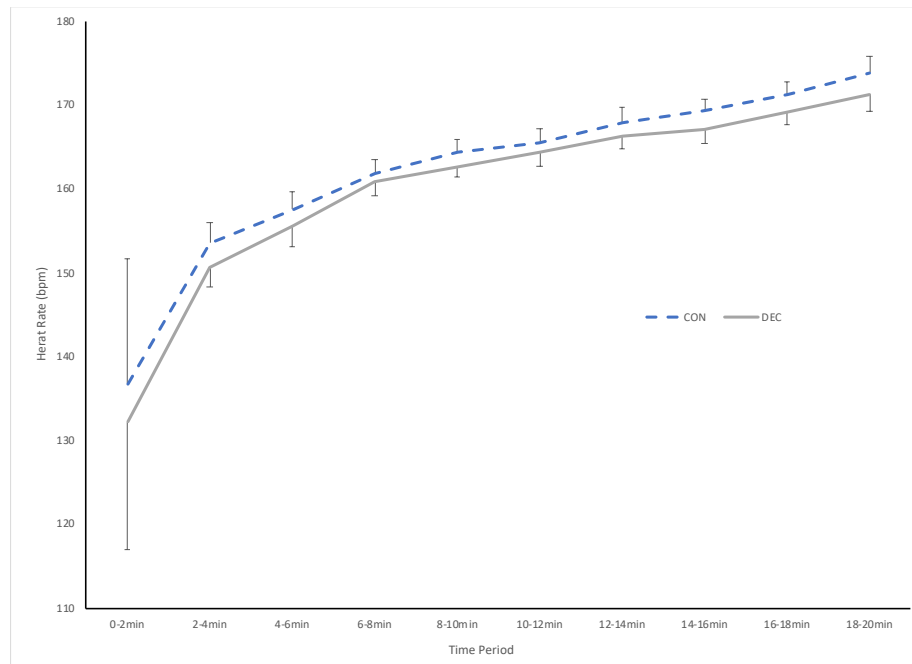


Figure 3. Mean heart rate for each 2 min period.

There was also no difference between conditions in blood lactate concentration. The $[BL]$ before the test was 2.1 ± 0.8 $\text{mmol} \cdot \text{L}^{-1}$ in the control condition and 1.5 ± 0.8 in the deception condition ($p=.124$; $d=.46$). After the test, the values were 10.5 ± 4.0 and 10.6 ± 3.6 $\text{mmol} \cdot \text{L}^{-1}$, respectively ($p=.936$; $d=.02$). There was a main effect of time ($F(1,12)=73.3$, $p<.001$, $\eta_p^2=.859$) but not a main effect of condition ($p=.448$) or an interaction ($p=.512$).

Due to the loss of some EMG data, results from only eight participants were used for analysis of this variable. The rmANOVA showed no main effect of condition ($p=.836$, $\eta_p^2=.007$) or time ($p=.142$, $\eta_p^2=.184$). The interaction was also not significant ($p=.993$, $\eta_p^2=.028$). The EMG activity for both conditions can be seen in Figure 4.

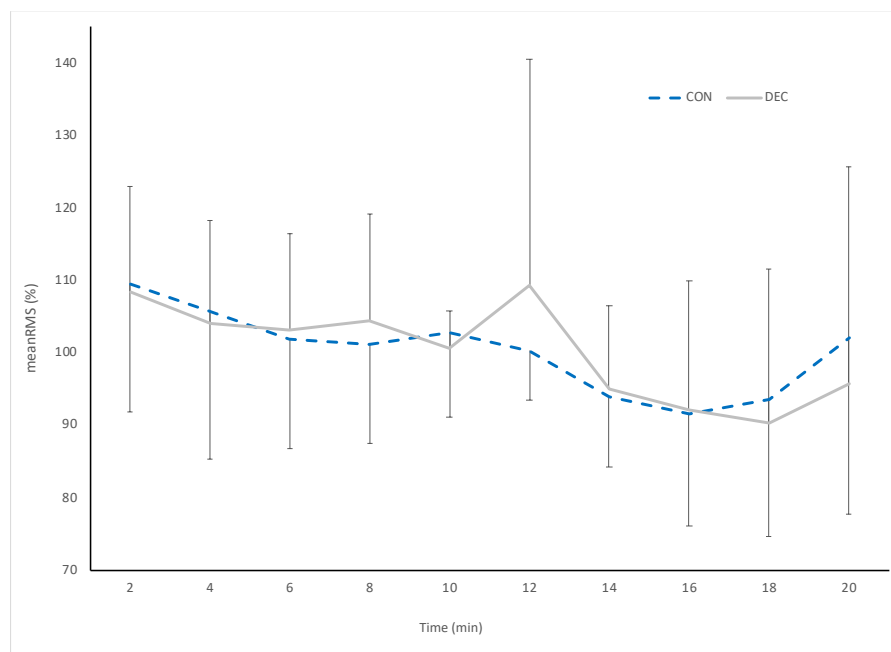


Figure 4. EMG activity throughout tests.

Discussion

The main purpose of this study was to explore the use of deception on performance during a cycling test. Specifically, we aimed to determine if biofeedback deception of heart rate would improve mean power output during a functional threshold power test. The results showed that there were no differences between the control and deception conditions, which suggests that biofeedback deception of heart rate alone was unable to improve performance. No differences were seen in any of the cycling or physiological variables. The cycling variables provided by the Wattbike are plentiful, but we chose to specifically explore mean values of cadence, speed, power, work, torque and force. Of these variables, there were no differences between conditions. There could be multiple reasons for the lack of improvement in performance under the deception condition, such as the chosen test protocol or the variable that was manipulated (i.e., HR), the presence of verbal encouragement, and the use of heart rate monitors in regular training.

Functional threshold power, or FTP, is defined as the highest average power output that can be maintained for approximately one hour²¹. The maximal power over an hour is predictive of performance on a time trial in elite cyclists²², and many cyclists routinely complete FTP testing to individualize exercise prescriptions²¹. While a full 60-minute test can be completed, it has been shown that shorter tests to predict FTP, such as the 20-min test, are highly reliable and valid²³ so it is suggested that the shorter tests are used in a laboratory setting. Once the FTP is known, it can help guide training and is thus very useful for athletes. The FTP can also be used as a performance test, rather than a traditional time-trial, as the mean relative power (W/kg) on an FTP been shown to be more correlated to actual cycling performance than $\text{VO}_{2\text{max}}$ ²⁴. Due to its widespread use and standardized length and protocol, the FTP test was chosen in the present study for the investigation of biofeedback deception. However, we found no difference between the conditions in average power or average relative power; this suggests that the deception was not beneficial for performance on the FTP test. This was corroborated with the EMG data, showing that there was no difference in lower limb muscle recruitment between conditions. Other testing protocol that could have been used include a time trial, critical power test, or a time to exhaustion (TTE). These tests all vary in length and set intensity level (i.e., they are arguably less standardized) but may provide different results than what was found using the FTP test.

Verbal encouragement is ubiquitous in many sports, and is a tool used by coaches and teammates to help motivate athletes with the expectation it will improve sport performance and enjoyment²⁵⁻²⁷. Verbal encouragement has been suggested as beneficial during exercise performance tests as well. For example, Andreacci et al.²⁸ studied the effect of verbal encouragement on maximal exercise testing. They found that frequent verbal encouragement (i.e., intervals of 20s) lead to significantly greater time to exhaustion on a maximal treadmill $\text{VO}_{2\text{max}}$ test compared to a control and a condition with a longer interval (60s or 180s). Other studies have found similar results²⁹. In the Castle et al.¹² study, verbal encouragement was provided along with the deception of core temperature and they found a significant improvement in performance. It is likely that in the present study, the deception of heart rate alone was not enough to fully elicit any performance gains. It is possible that encouragement is a moderating variable that influences the effect of biofeedback deception on cycling performance. Future studies should test this assertion and design an experimental protocol around this variable.

When questioned about training, more than half of the participants (8 out of 13) in the present study reported that they do not routinely utilize HR data to monitor exercise intensity. Given that the majority of participants could be assumed to be less inclined to focus on their heart rate during the test and were not explicitly instructed to do so by the researchers, it may be the case that deception of exercise heart rate is more effective when implemented with athletes that regularly monitor their heart rate during training. Future research should attempt to implement heart rate deception when administering performance testing to individuals that report that they regularly utilize heart rate data during training sessions.

Conclusions

Very few studies have attempted to deceive participants by providing inaccurate data relating to a physiological variable. Most research focusing on deception during performance testing has concentrated on deceiving participants of a performance variable such as power output, speed, or general pace. This study's results provide evidence suggesting that biofeedback deception of heart rate alone is unable to improve performance on an FTP test. Verbal encouragement may be a vital moderating variable that allows successful biofeedback deception to occur. It is recommended that future studies take this into consideration.

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