# Effect of Distance Feedback on Pacing Strategy and Perceived Exertion during Cycling

YUMNA ALBERTUS, ROSS TUCKER, ALAN ST CLAIR GIBSON, ESTELLE V. LAMBERT, DAVID B. HAMPSON, and TIMOTHY D. NOAKES

*MRC/UCT Research Unit for Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, the University of Cape Town and the Sports Science Institute of SOUTH AFRICA, Cape Town, SOUTH AFRICA*

**ABSTRACT**

ALBERTUS, Y., R. TUCKER, A. ST CLAIR GIBSON, E. V. LAMBERT, D. B. HAMPSON, and T. D. NOAKES. Effect of Distance Feedback on Pacing Strategy and Perceived Exertion during Cycling. *Med. Sci. Sports Exerc.*, Vol. 37, No. 3, pp. 461–468, 2005. **Purpose:** The aim of this study was to investigate whether providing incorrect distance feedback would alter pacing strategies, perceived exertion, and heart rate during 20-km cycling time trials (TT). **Methods:** Well-trained cyclists ($N = 15$) performed a peak power output (PPO) test, familiarization trial, and four 20-km cycling TT during which they were provided with only distance feedback using 1-km distance splits. For the control trial, subjects received accurate feedback at each kilometer split. In the increase trial, they received inaccurate feedback at 0.775 km for the first kilometer split with the distance increasing by 25 m each subsequent split up to 1.25 km in the final kilometer split. For the decrease trial, inaccurate feedback was provided at 1.25 km for the first kilometer split with the distance decreasing by 25 m each subsequent split up to 0.775 km in the final split. For the random trial, distance splits were randomized. **Results:** No significant differences were found in the finishing times between trials. Pacing strategies were unaltered as suggested by similar power output profiles during all trials. RPE scores were also similar for all trials. However, average heart rate varied significantly between trials ($P < 0.05$). **Conclusions:** These results suggest that exercise performance, pacing strategy, and RPE during a 20-km cycling TT are not altered by incorrect distance feedback. The data supported the existence of a pacing strategy that is set before exercise and that is unaffected by external distance feedback. **Key Words:** EXERCISE PERFORMANCE, FEEDFORWARD, TELEOANTICIPATION, AFFERENT SIGNALS

Well-trained athletes employ "pacing strategies" to optimize performance during cycling and distance running (8). However, what is not clear is the extent to which pacing is affected by intrinsic physiological factors such as heart rate response, ventilation, and changes in the humoral milieu, compared with environmental (wind and temperature) (1) and extrinsic or external cues (16). Further, there is evidence that response to both external and intrinsic feedback may alter or dissociate central control of pacing strategies by, for example, the use of central acting drugs (5) and hypnosis (15). In addition, Ulmer (29) has proposed that biomechanical as well as metabolic information is fed back to the brain and this peripheral input and its central integration are essential for planning of subsequent exercise intensity. Feedforward control also occurs from the central nervous system, whereby the analysis of past experiences presets the exercise intensity for future exercise bouts (29). This integrative process, which culminates in the selection of a specific workload or exercise intensity, apparently occurs at the level of the subconscious and has been termed "teleoanticipation" (29). A further component of the teleoanticipatory mechanism is the length of time or distance involved in the exercise (29).

Perception of effort also appears to be important in precisely regulating exercise performance (16,19). Perceived exertion is created by the integration of multiple afferent signals from a variety of perceptual cues such as cardiopulmonary factors (ventilatory rate, heart rate, and oxygen uptake) and metabolic/peripheral factors (blood lactic acidosis, mechanical strain, and skin temperature) (14). It is currently unknown how conscious and subconscious physiological afferents interact to produce the perception of effort. Previous research in our laboratory has shown that

Address for correspondence: Yumna Albertus, MRC/UCT Research Unit for Exercise Science and Sports Medicine, Sports Science Institute of South Africa, PO Box 115, Newlands, 7725, South Africa; E-mail: yalbert@sports.uct.ac.za.
Submitted for publication August 2004.
Accepted for publication November 2004.

0195-9131/05/3703-0461
MEDICINE & SCIENCE IN SPORTS & EXERCISE®
Copyright © 2005 by the American College of Sports Medicine
DOI: 10.1249/01.MSS.0000155700.72702.76



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

the general perception of effort is not altered in runners who receive incorrect external feedback concerning their running intensity during constant-load exercise (10). Several other studies have also investigated the effects of external feedback on ratings of perceived exertion (RPE). Thus Zohar and Spitz (30) provided subjects with either no, partial, or full feedback of the distance covered during the previous 3 min of activity. They found that there was a decrease in performance in the no feedback trial; however, RPE were similar in all three trials.

Rejeski and Ribisl (21) evaluated the role of expected exercise duration on the perception of effort. They found the subjects' RPE were lower even though physiological variables did not change when they were told they would be cycling for 30 min as opposed to 20 min, but when the exercise was terminated after only 20 min. In addition, the effects of distance feedback were studied by Nikolopoulos et al. (16). They evaluated pacing strategies during trials in which subjects were not informed of the distance they had cycled, but were asked to report their perception of how far they had cycled. It was found that the subjects cycled at similar power outputs and heart rates during the time trials (TT) they perceived to be the same distance, even though the distances they actually rode varied from 34 to 46 km.

The available literature therefore suggests that external feedback may have variable effects on both perceived exertion and physiological responses. But the precise influence has yet to be documented. It is not clear how time or distance deception affects RPE and pacing strategies, particularly in self-paced performance trials. One of the problems with most research in this field is that study protocols have involved prescribed workloads for a set duration, whereas most athletic endeavors involve self-paced exercise at a self-chosen intensity.

Therefore, the primary aim of this study was to determine the extent to which incorrect distance-splits feedback alters RPE, physiological variables, and pacing strategies during a 20-km cycle TT. By providing deceptive feedback, we wished to distinguish whether the conscious and subconscious physiological afferents that interact to produce the perception of effort could be dissociated.

## METHODS

### Subject Selection

Fifteen competitive, endurance-trained male cyclists volunteered for this study. Subjects gave their written informed consent before testing. A physical activity readiness questionnaire (PAR-Q) was administered to all subjects before participation to ensure that they represented a group at low risk for exercise. The subjects were unaware of the deceptive nature of this study. However, after all the subjects were tested, they were debriefed about the complete protocol, including the deceptive feedback. The study was approved by the research and ethics committee of the Faculty of Health Sciences within the University of Cape Town.

### Experimental Design

Upon recruitment, subjects were informed that they would participate in a validity/repeatability study involving a peak power output (PPO) test, familiarization trial, and four various distance feedback cycling TT, during which they were provided only with distance feedback using 1-km distance splits. However the feedback was deceptive, and in only one trial were subjects given correct feedback. The order of the trials was randomized for each subject. During the control trial (CON), they were provided with correct 1-km distance splits (honestly informed of the distance cycled). During the increase trial (INC), distances were increased by 25-m increments starting at 0.775 km (in which they were told that they had cycled 1 km), 0.8 km (for the second kilometer, when they were told that another 1 km had been cycled) up until the last kilometer where they actually cycled 1.25 km. During the decrease trial (DEC), distances were decreased throughout the trial, so that during the first kilometer, subjects actually cycled 1.25 km. This distance decreased by decrements of 25 m for each subsequent kilometer so that they had actually cycled 1.25 km when they were informed that 1 km was completed. During the second kilometer they had cycled another 1.225 km when they were informed that another 1 km had been completed up until the final (20th) kilometer where they actually cycled 0.775 km. During the random trial (RAN), they were provided with randomly assigned distances that either increased or decreased by 25–250 m for each 1-km distance split, but were told that they had cycled for 1 km at each split. As a result of combinations, each subject cycled a total of 250 m further for the three deceptive trials (Table 1), totally a covered distance of 20.25 km. The effect of the increased distance on pacing strategies was also compared to the honestly informed 20-km control trial.

### Preliminary Testing

Subjects first reported to the laboratory for anthropometric measurements and to perform a PPO test. Percent body fat was calculated using the equations of Durnin and Wormersley (6) from skinfold measurements taken at four sites.

PPO (described below) was determined after a 10-min warm-up on the Kingcycle ergometer (Kingcycle, High Wycombe, UK). The starting power output was determined by multiplying the subject's body mass by 3 W. The cycling

TABLE 1. Actual distance cycled for trials when given 1-km distance splits.

| Distance (km) | Control (km) | Random (km) | Increase (km) | Decrease (km) |
|---|---|---|---|---|
| 2 | 2 | 2.125 | 1.575 | 2.475 |
| 4 | 4 | 3.975 | 3.250 | 4.850 |
| 6 | 6 | 6.075 | 5.025 | 7.125 |
| 8 | 8 | 8.150 | 6.900 | 9.300 |
| 10 | 10 | 10.425 | 8.875 | 11.375 |
| 12 | 12 | 12.125 | 10.950 | 13.350 |
| 14 | 14 | 13.850 | 13.125 | 15.225 |
| 16 | 16 | 15.900 | 15.400 | 17.000 |
| 18 | 18 | 18.250 | 17.775 | 18.675 |
| 20 | 20 | 20.250 | 20.250 | 20.250 |

Distance covered when given 1-km splits for deceptive trials compared with distance covered in the control trial.



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

load was subsequently increased by 20 $W \cdot min^{-1}$. The subjects were required to match a continuously increasing power output displayed in analog form on the computer monitor. The test was terminated when the subject failed to match the target power output. The highest mean power output achieved during any 60-s period was recorded as the subject's PPO.

### Familiarization Trial

After measurement of PPO, subjects reported to the laboratory on five separate occasions. During the first visit, subjects familiarized themselves with the Kingcycle ergometer as well as the RPE scale described subsequently. Thereafter, they completed a familiarization 20-km TT.

### Familiarization of the Rating of Perceived Exertion Scale (RPE Scale)

Levels of subjective perceived exertion were quantified using the Borg category–ratio scale. Printed instructions were provided to familiarize subjects with the scale before testing. Instructions were given for the RPE scale as suggested by Pandolf (19). The Borg category–ratio scale was used to quantify perceived overall exertion during the TT. Subjects were exposed to this scale twice before experimental trials, once during the PPO test and once during the familiarization trial.

The category–ratio scale was selected to measure overall exertion because the growth of this scale more closely parallels the exponential increase in many of the parameters associated with peripheral exertion (i.e., ventilatory rate, blood lactic acidosis, and perceived muscular strain) (18). As suggested by Borg (2), subjects were instructed to use decimals where appropriate, as well as produce ratings below and above the limits of the scale (0.5–10) if necessary. Once instructions were given and questions were answered to the subject's satisfaction, no further assistance was provided by the investigator in translating sensations to the numerical ratings on the RPE scales during the TT.

### Kingcycle Ergometry System

The PPO test and four TT utilized the Kingcycle ergometry system. Using this system, subjects mounted their own racing bicycles to the ergometers. After the removal of the front wheel, the subject's bicycle was attached to the ergometer by the front fork and supported by an adjustable pillar under the bottom bracket. The bottom bracket support was used to position the rolling resistance of the rear wheel correctly on an air-braked flywheel. A photooptic sensor monitored the velocity of the flywheel in revolutions per second (RPS) from which an IBM-compatible computer calculated the power output (W) that would be generated by a cyclist riding at that speed on a level terrain, using the following equation:

$$W = 0.000136\ RPS^2 + 1.09\ RPS \qquad [1]$$

The Kingcycle was calibrated before the PPO test, familiarization, and the four TT. For the calibration, subjects were asked to accelerate to a workload of 115 W and instructed to immediately stop pedaling as soon as they reached the desired workload, while remaining seated in their riding position. The bottom bracket support was then adjusted until the computer display indicated that the slowing of the flywheel matched a predetermined reference power decay curve.

### 20-km Time Trials

Subsequent to the PPO test, subjects performed four, 20-km TT separated by 6–8 d, with only light training permitted over the 24 h preceding each trial. The trials were performed on the Kingcycle ergometry system described above. Throughout each trial power output was monitored continuously, averaged every minute and stored on the Kingcycle ergometer computer. This allowed each subject's power output for every minute to be recorded to document the pacing strategy used throughout each TT. The time taken to complete the TT was also monitored and stored on the Kingcycle computer. Heart rate was monitored continuously and recorded at 5-s intervals throughout the TT using a Polar Vantage XL heart rate monitor (Polar Electro OY, Kempele, Finland).

For all four of the 20-km TT, the following procedure was followed. To prevent any possible external source of feedback, watches, the Kingcycle computer screen, and the heart rate monitor were all placed out of the vision of subjects. Each subject wore ear insulators to attenuate any sound feedback from the bicycle wheels. The subject's bicycle was placed on the ergometer and calibrated. After this, each subject performed a 10-min warm-up period at a self-selected intensity. At the end of the warm-up period, the investigator verbally signaled that the trial had begun. During the TT, the investigator signaled that 1 km was completed, and the subject provided ratings of effort on the Borg category–ratio scale. The instantaneous power and heart rate were recorded at "each 1 km" as well as the time taken to complete "each 1 km." The different TT were carried out as previously described. The four trials were completed in random order.

### Statistical Analysis

**Relationship between trials for all variables.** We estimated that in detecting differences in 20-km TT performance of 1 min with a standard deviation of 1.8 min, using paired data on repeated measures at an alpha level between 0.05 and 0.02, and a statistical power of 80% that we required between 13 and 17 subjects. Data are presented as mean ± SD. Significant differences between time taken to complete each kilometer, heart rate, power output, and RPE were assessed using analyses of variance with repeated measures. Correlation coefficients for RPE were calculated for all trials.

**Area under the curve.** The nature of the feedback and deception differs between trials, for example, during the



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

TABLE 2. Subject characteristics ($N$ = 15).

| Variable | Mean and Standard Deviations |
|---|---|
| Age (yr) | 25 ± 8 |
| Height (m) | 1.76 ± 0.1 |
| Mass (kg) | 69 ± 7.5 |
| Max heart rate (bpm) | 191 ± 7 |
| % Body fat | 11.4 ± 3 |
| PPO (W) | 397 ± 58 |
| P/mass ratio (W·kg$^{-1}$) | 5.7 ± 0.7 |

PPO, peak power output; P/mass ratio (power produced per kilogram body mass), power to mass ratio. All values represented as mean ± SD.

increase trial, subjects cycled less than 1-km splits for the first 10 km and then cycled more than 1-km splits for the second 10 km. As a result, we compared effort perception and the physiological responses for the first 10-km split and the second 10-km split by analyzing the area under the curve for each variable during each trial. Statistical significance was then measured using analysis of variance with repeated measures.

**Coefficient of variation.** Variability in power output, HR, and RPE over the course of each trial were examined by determining the coefficient of variation (CV %) measured as mean/SD × 100. All results were analyzed for statistical significance ($P < 0.05$) on a commercial software program (Statistica 6, StatSoft. Inc.©). When a significant $P$ value was obtained, a Tukey's HSD *post hoc* test was used to identify specific differences.

## RESULTS

The descriptive characteristics of the research subjects are shown in Table 2. Data are indicative of subjects being well trained and physically fit.

Despite receiving verbal cues at distances not corresponding to the actual distance covered in the deception trials (Table 1), the time taken to complete the distance did not differ between trials (Table 3). The average cycling speed ranged from 42.1 ± 1.5 km·h$^{-1}$ in RAN and 43.2 ± 0.1 km·h$^{-1}$ in CON, and were not significantly different.

Figure 1 shows the average power output (A), RPE (B), and heart rate (C) measured during trials expressed as a percentage of total time to allow comparisons between trials that were of different duration. The pattern of response was the same irrespective of whether the data were analyzed per kilometer, per minute, or as a percentage of total time. Data were subsequently analyzed up to 95% of trial duration because it was considered that the significant increase in the variables during the final 5% of all trials would mask any

TABLE 3. Time to complete each trial.

| Trial | Finish Time (min) | Average Speed (km·h$^{-1}$) |
|---|---|---|
| Control | 28.4 ± 1.6 | 43.2 ± 0.1 |
| Random | 28.7 ± 1.4 | 42.1 ± 1.5 |
| Increase | 28.6 ± 1.5 | 42.8 ± 1.1 |
| Decrease | 28.4 ± 1.1 | 42.8 ± 0.9 |

Time is expressed in minutes and seconds/60. Neither finishing times nor cycling speeds were significantly different from the control trial. No significant difference found for average speed between trials. All values are presented as mean ± SD.

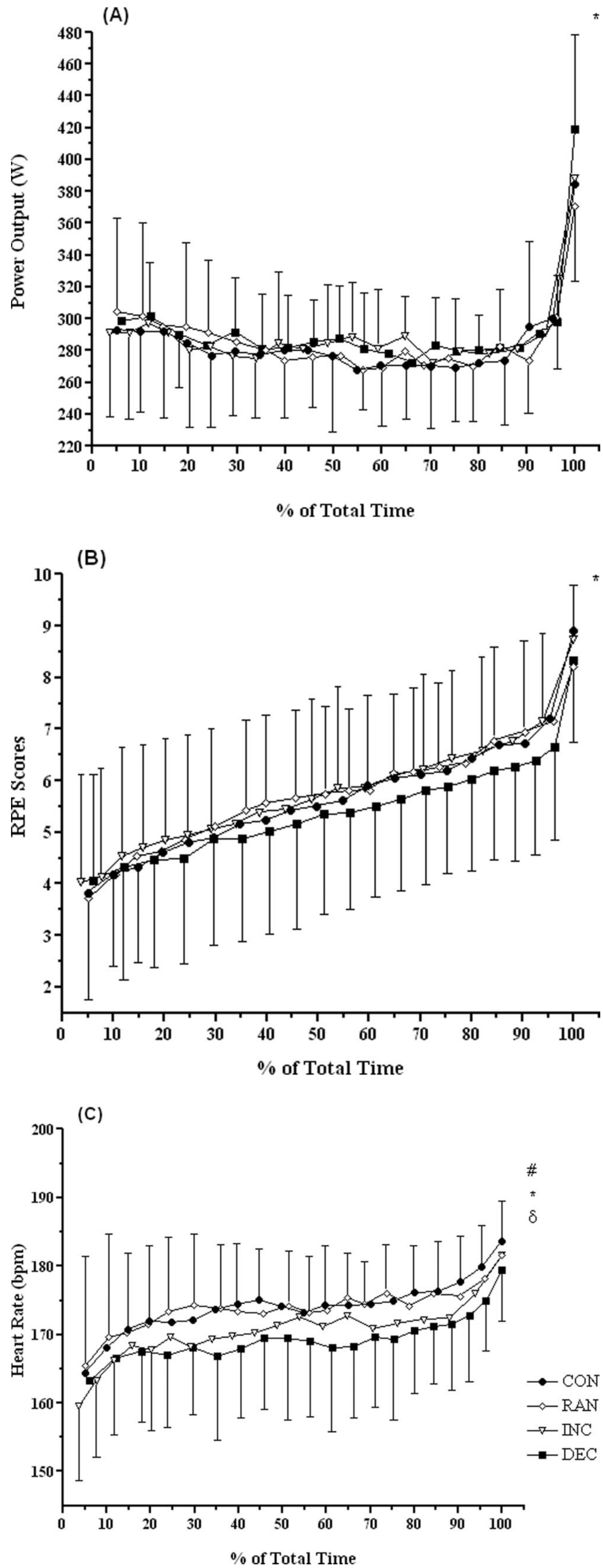


**FIGURE 1—Mean values for power output, heart rate, and rating of perceived exertion (RPE) scores for all four 20-km TT. Significant difference between trials, # $P < 0.05$ over 95% of total time. Significant time effect, * $P < 0.0001$ for each trial. Significant interaction effect between trial and percentage of time, δ $P < 0.05$.**



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

TABLE 4. Coefficient of variations for all trials.

| Trial | 10 km | Power (%) | RPE (%) | Heart Rate (%) |
|---|---|---|---|---|
| Control | 1st | 6.3 ± 3.3 | 15.2 ± 13.1 | 2.5 ± 1.7 |
| | 2nd | 7.3 ± 3.8 | 9.5 ± 4.5 | 1.8 ± 1.4 |
| Random | 1st | 8.1 ± 4.0 | 16.7 ± 10.2 | 2.6 ± 2.8 |
| | 2nd | 8.0 ± 4.3 | 8.0 ± 4.7 | 1.6 ± 0.7 |
| Increase | 1st | 8.3 ± 8.1 | 13.6 ± 14.3 | 2.7 ± 1.8 |
| | 2nd | 6.7 ± 3.6 | 9.9 ± 7.9 | 1.7 ± 1.5 |
| Decrease | 1st | 6.3 ± 2.8 | 13.7 ± 12.8 | 2.1 ± 1.0 |
| | 2nd | 6.1 ± 2.6 | 8.1 ± 4.1 | 1.9 ± 1.4 |

Coefficients of variation calculated over 95% of total time taken to complete each trial. RPE, ratings of perceived exertion. No significant differences were found between trials for all variables. Values are presented as mean ± SD.

differences during trials. Power output decreased progressively from the start of the trial and became significantly lower than the starting power output (296 W) from 55 to 65% (274–275 W) and from 70 to 75% (274–275 W) of total time. The power output then increased and returned to levels similar to those measured at the start of the trial at 95% (297 W) of total time, before increasing significantly again at the end of trial. No significant differences were found in power output between trials (Fig. 1A).

RPE was not significantly different between the trials. RPE increased significantly over time for all trials ($P < 0.0001$) and became significantly higher than the initial RPE (3.9) from 20% (4.6) to 95% (7.3) of total time (Fig. 1C), but was not significantly different between trials. RPE was found to increase linearly showing correlations for CON $r = 0.98$, RAN $r = 0.96$, INC $r = 0.98$, and DEC $r = 0.99$ ($P < 0.0001$ for all trials).

However, average heart rate was significantly different between the trials ($P < 0.05$), and also increased over time ($P < 0.0001$). The average heart rate in DEC (171.8 ± 8.5 bpm) was significantly lower than CON (176.9 ± 6.6 bpm) and RAN (176.3 ± 7.8 bpm) (Fig. 1C). There was a significant interaction effect between trials over time ($P < 0.02$). From 30 to 45% of trial duration and at 60% of total time HR during DEC was lower than CON, although there was a tendency for HR to be lower throughout the entire trial. During INC, heart rate was also significantly lower than in CON at 35 and 95% of total time (168 and 172 bpm vs 174 and 178 bpm), respectively.

The coefficients of variation (CV%) for power output, HR, and RPE are shown in Table 4. No significant differences were found between the control trial and the deception trials for all variables, indicating that the variability in response over each split was not affected by the nature of the feedback regarding distance covered.

The area under the curve for each 10-km interval within trials is shown in Table 5. Significant differences were found between the first and second 10-km intervals in each trial for HR and RPE ($P < 0.05$); however, there were no between-trial differences for RPE. Area under the curve for power output (total work done) was not different in the second 10-km interval compared with the first 10-km interval within each trial. For heart rate, the area under the curve for DEC (first 10 km, 1509 ± 92; second 10 km, 1542 ± 83) was significantly lower to CON (first 10 km, 1547 ± 88; second 10 km, 1586 ± 63) for both the first and second 10-km intervals.

TABLE 5. Area under the curve for all trials.

| Trial | 10 km | Power (W) | RPE | Heart Rate (bpm) |
|---|---|---|---|---|
| Control | 1st | 2548 ± 407 | 43 ± 16* | 1547 ± 88* |
| | 2nd | 2549 ± 311 | 59 ± 15 | 1586 ± 63 |
| Random | 1st | 2589 ± 366 | 45 ± 15* | 1549 ± 95* |
| | 2nd | 2541 ± 244 | 59 ± 14 | 1581 ± 64 |
| Increase | 1st | 2549 ± 402 | 44 ± 18* | 1511 ± 92* |
| | 2nd | 2597 ± 267 | 58 ± 16 | 1556 ± 83 |
| Decrease | 1st | 2593 ± 248 | 43 ± 18* | 1509 ± 92#* |
| | 2nd | 2617 ± 210 | 56 ± 15 | 1542 ± 83 |

The areas under the curve for all trials were divided into two 10-km halves of the 20-km time trials. The first 10 km being from 1 to 10 km and the second 10 km being from 11 to 20 km. Values presented as mean ± SD.
Significant differences between 10-km halves within each trial; * $P < 0.05$.
Significantly different from the control trial; # $P < 0.05$.
All values are presented as mean ± SD.

## DISCUSSION

The primary aim of this study was to determine whether the provision of incorrect distance feedback altered pacing strategy, heart rate, and perception of exertion during self-paced 20-km cycling TT. The most significant finding was that subjects had similar 20-km TT finishing times (Table 3) irrespective of whether they were provided with correct or incorrect distance splits. Their performance was therefore not influenced by this nonmonotonic distance feedback. This occurred despite the cumulative mismatch between actual and completed distance being as large as 1.375 km (Table 2), representing differences per kilometer of 250 m. For example, during DEC, the subjects were informed that 10 km had been completed, when in fact 11.375 km had passed. At the speeds recorded during the present study (43 $km \cdot h^{-1}$), this corresponds to a time difference of approximately 1 min and 30 s between the time that the subjects had actually completed the distance and when they were informed. Yet, despite this apparently large difference, the subjects did not alter their power output in response to the progressive increase in the mismatch between actual and completed distance. Rather, it appears that other factors unrelated to the distance feedback they received were responsible for the pacing strategy they adopted. Furthermore, because this pacing strategy was fixed throughout exercise, it appears as if it was determined before exercise, that is, apparently "hardwired" already at the onset of the exercise.

Indeed, it has recently been suggested that the pacing strategy or power output adopted during self-paced exercise is regulated in a subconscious feedforward manner (13,26,29). Such regulation would occur in an anticipatory manner based on expectations of exercise duration, before commencement of the trial. Ulmer (29) suggested that exercise intensity is initially set by feedforward commands and this initial intensity is adjusted during the bout by either physiological or external feedback, to prevent potentially expending too much energy, a process he termed "teleoanticipation." Our data suggest that this anticipatory response may be more critical in regulating pacing than performance feedback once the exercise bout has begun.



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

We also found that the variability in pacing strategies was not different between trials, as indicated by the similar coefficients of variation for power output (Table 4). This is further supported by the slight variation of power output in the first and second 10 km for all trials (Table 5). The similar variability in power output between trials and between the first and second half of each trial suggests that although subjects may have made minor adjustments in pacing in response to distance information, they reverted to the same overall pacing strategy to complete the TT.

Further evidence for teleoanticipatory pacing strategies is evident from the pattern demonstrated in the last kilometer for all trials, where all subjects were capable of significantly increasing their power output, irrespective of the distance feedback provided. We propose that subjects may have "constrained" themselves throughout the trials to prevent the development of absolute or premature fatigue, while still performing the TT to the best of their ability. Indeed, this significant increase in power output is a characteristic finding in trials in which either the duration (11,21,27) or distance (26,30) is known, and agrees with Hampson et al.'s (9) interpretation of teleoanticipation whereby, during a competitive event, an athlete attempts to complete a set distance in the fastest time possible but within physiological limits. Thus, the athlete sets the work output at the onset of exercise, such that the task will be completed successfully. The final kilometer acceleration is an indication of the maintenance of a reserve capacity allowing the power output to increase over the last kilometer secondary to an increase in central neural drive to the exercising muscles (11,28). It has been suggested that this pacing strategy is refined to some degree by their prior cycling experiences (26,29).

In the present study we found that RPE was similar in all trials (Fig. 1B). It has been suggested that RPE is sensitive to changes in work rate (28). Pandolf (19) proposed two categories of physiological factors that are major determinants of RPE during physical exercise. These are factors of local origin relating to feelings of strain from exercise muscles and/or joints, and central factors primarily relating to cardiopulmonary sensations. Numerous studies have shown associations and dissociations between RPE and certain of these factors (9). In a previous study, Hampson et al. (10) found that RPE and running speed could be dissociated during running exercise when subjects expected the running speed, imposed by the experimenter, to increase when in fact the speed was deceptively held constant. The results of present study support a dissociation between RPE and work rate because we found that RPE increased linearly during all four trials, whereas power output first decreased over time, then increased again. Rather, as discussed subsequently, it is clear that the RPE is determined by the duration of exercise that remains (17) or, more likely, the expected duration of exercise at the start of the exercise bout.

Power decreased progressively from 55 to 65% (274–275 W) and from 70 to 75% (274–275 W) (Fig. 1A). This decrease in power therefore occurred while RPE was progressively increasing (Fig. 1B). Power then increased at 75–95% of total time (Fig. 1A) when RPE was significantly greater than before. Thus, it appears that RPE was dissociated from the work rate, as the changes in power output over time were not tracked by the changes in RPE. The generation of the RPE is therefore not the result of only physiological factors but may have been regulated by psychological and subconscious processes present already at the onset of exercise, as has been suggested (15,17,25,30).

In a previous study, Zohar and Spitz (30) had subjects perform a 45-min cycle TT consisting of 15 trials lasting 3 min each, during which they received performance feedback (distance traveled in meters). Based on this feedback, subjects were asked to predict their performance for an upcoming 3-min trial and to rate their perceived exertion. It was found that predicted and actual performances were not different in the groups who received full (received feedback following each trial) and partial feedback (received feedback following trials 1, 6, and 11). However, performance in the group receiving no feedback was worse than expected even though actual perceived exertion and HR increased similarly between the three conditions. This indicated that the underperformance in the no feedback trial (compared with the expectation of performance) occurred independently of changes in measured RPE. That study also supports the hypothesis that the RPE is set from the start of the exercise (17,25) and that different levels of feedback have no effect on the rating of perceived exertion. Those authors concluded that physiological sources other than heart rate play a role in the perception of effort, but they did not consider the possible role of teleoanticipation on the RPE.

A study by Rejeski and Ribisl (21) indicated the importance of knowledge of exercise duration and the anticipatory "setting" of the RPE during exercise. A running trial of 20 min was compared with a subsequent trial in which subjects were told before commencing exercise that they would be exercising for 30 min, but exercise was terminated after only 20 min. The subjects' RPE was lower at 20 min when they expected to run for 30 min, indicating that RPE is based, at least in part, on the expected duration of the upcoming exercise bout, and can be different even though exercise intensity and physiological variables are not different. The perception of effort may be suppressed in the trial that is expected to be longer, possibly to ensure that premature fatigue is avoided. Thus, the RPE cannot be merely a product of exercise related feedback signals or exercise intensity but could be a conscious interpretation of fatigue that may be altered either subconsciously or consciously before commencement of the trial, so that even while running at the same speed, the RPE can differ significantly.

Despite similar power and exertion profiles, heart rates varied significantly between trials in this study (Fig. 1), so that the heart rate in DEC was significantly lower than during CON and RAN trials (Fig. 1B). Of note is the finding during DEC in which subjects were informed that they had cycled 10 km, when in fact they had completed 11.375 km. Yet the area under the curve for heart rate (area = 1509 ± 92) was significantly lower than in CON (area = 1547 ± 88) and RAN (area = 1549 ± 95) (Table 5). This indicates a dissociation between heart rate and exercise performance,



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

RPE, and power output. These results also highlight the fact that heart rate responses are not solely associated with differences in RPE and do not agree with Borg's concept that heart rate might serve as a perceptual signal or mediator for exertion (3). The majority of Borg's evidence linking heart rate and perceptual signals of exertion was derived by analyzing correlation data. Studies have shown good correlations between heart rate and RPE while lifting weights (2). However, numerous studies (4,7) have shown that whereas heart rate is strongly correlated with RPE, these two variables can be dissociated from each other under certain conditions (5,19,22), and the present results extend this finding further. If RPE is set in anticipation of the expected exercise duration, it will be higher at higher work rates that will naturally be of shorter durations. Because heart rate will also be higher at higher work rates, a spurious, not causal, relationship between heart rate and RPE will be revealed.

Power output/pacing strategy was also not influenced directly by heart rate, as similar time course changes were observed as for RPE (Fig. 1B), with the greatest power output being achieved when heart rate, a measure of cardiovascular demand, was highest. The increase in power output at the end of the trials would indicate that the adopted pacing strategy is not merely a consequence of direct effects of cardiovascular or other factors, possibly muscular strain. Rather we propose that this forms part of a complex system (12,24) that regulates the perception of effort in a feedforward manner and alters power output specifically to ensure that the perceived exertion does not become maximal or excessively high before the end of the trial.

It has recently been suggested that the rating of perceived exertion is set at the beginning of the exercise bout and is regulated by feedback/sensory variables (17,24,25). Thus, it is proposed that the rate at which RPE increases during exercise to exhaustion at a constant workload is subconsciously controlled, such that the total exercise time to exhaustion (which occurs when the RPE reaches the maximal tolerable level) is dependent on the rate of increase in RPE. Because RPE was found to increase linearly in the present study (when expressed as a function the percentage of total time, as proposed by Noakes (17)), we speculate that even at the onset of exercise, when the RPE is submaximal, the rate of increase in RPE has been set. Such a finding can be explained if the RPE is set either before the onset or very shortly after exercise begins.

In the present study, exercise was self-paced, and hence the rate of increase in RPE could be modified by the adjustment of power output. Thus, we propose that the anticipated rate at which RPE increases is set before exercise begins, and the time-course changes in power output are achieved to ensure that the actual rate of increase in RPE does not exceed this preset rate. Teleologically, such an anticipatory system would serve to ensure that homeostasis is maintained (12,24,25) while the exercise trial is performed to maximal volitional levels, as the feedforward setting in power output and subsequent adjustments in RPE would be influenced by physiological resources and different feedback (12,26). In other studies, the availability of fuel reserves (20) and elevated body temperature or heat storage (28) have been proposed to alter the absolute rate of increase in RPE in an anticipatory manner. The mechanism for such regulation is not known, but the result would be to allow a higher power output to be selected very early on during trials in specific conditions, if the distance is known. This has been shown previously (28), and the present study indicates that even the provision of incorrect distance feedback does not influence the adopted pacing strategy. Rather, we speculate that since the subjects were blinded to their power output, heart rate, and time, their power output (and adjustments thereof) would be set based on this anticipatory calculation, and modified by afferent feedback, which is unaffected by externally provided distance information. The prior experience of performing a 20-km cycle could have possibly played a more significant role in their pacing strategy and thus provision of distance feedback was not taken into account. Indeed we have shown that prior experience is necessary to produce reproducible self-paced performances (22,23).

One of the limitations of this study was the small mismatches between actual and completed distance that cumulatively produced mismatches of approximately 1 min 30 s, as described. It may be these differences were too small to cause changes in pacing strategies. However, preliminary testing suggested that larger increments would have made it too obvious to the subjects that they were being deceived. It is acknowledged that the average cycling speeds may not be significantly different during the trials; however, during an actual competitive performance, this slight difference in speed could produce a significantly faster time over longer distances. Further, a 20-km TT may have been of insufficient distance, whereas incorrect feedback could possibly have produced significant changes in anticipatory pacing strategies a more fatiguing endurance trial of several hours. And the finding of the present study, that pacing strategy is not altered in the presence of incorrect distance provision, would likely be even more prominent in highly trained time-trial specialists, as training and previous experience are vital factors in the regulation of exercise performance according to the model proposed. Further research is necessary to examine these possibilities.

In summary, these results demonstrate that exercise performance and pacing strategies are not altered by the provision of incorrect distance feedback. We propose that subjects pace themselves according to their level of perceived exertion and possibly physiological factors other than heart rate. We also suggest that the RPE is set in a feedforward manner from the start of exercise and that changes in power output are regulated specifically to ensure that the RPE rises as a linear function of exercise duration and that the trial is completed without bodily harm. The rate of increase in RPE was not different between trials, suggesting that the proposed anticipatory setting of RPE is insensitive to incorrect distance feedback. This shows that an exercise task can be completed without the attainment of a maximal, limiting RPE and, importantly, within the limits of exertion by incorporating multiple afferents signals from a variety of sensory cues but is unaffected by inaccurate distance feed-



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

back at the levels provided in the present study. Future research should include the investigation of distance feedback over longer distances with perhaps slightly larger distance increments and decrements. Further understanding is needed to establish how the athletes anticipate the total distance or duration of the exercise being performed and what factors, other than expected exercise duration (21), affect the anticipatory setting of the RPE.

The Medical Research Council of South Africa, Benfara Scholarship Fund University of Cape Town, and the Nellie Atkinson and Harry Crossley Staff Research Funds of the University of Cape Town provided funding for this study.

## REFERENCES

1. Atkinson, G., and A. Brunskill. Pacing strategies during a cycling time trial with simulated headwinds and tailwinds. *Ergonomics* 43:1449–1460, 2000.
2. Borg, G. A. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exerc.* 14:377–81, 1982.
3. Borg, G. A. Perceived exertion: a note on "history" and methods. *Med. Sci. Sports Exerc.* 5:90–93, 1973.
4. Cafarelli, E., and B. J. Noble. The effect of inspired carbon dioxide on subjective estimates of exertion during exercise. *Ergonomics* 19:581–589, 1976.
5. Davies, C. T., and A. J. Sargeant. The effects of atropine and practolol on the perception of exertion during treadmill exercise. *Ergonomics* 22:1141–1146, 1979.
6. Durnin, J., and J. Womersley. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br. J. Nutr.* 32:77–97, 1974.
7. Edwards, R. H., A. Melcher, C. M. Hesser, O. Wigertz, and L. G. Ekelund. Physiological correlates of perceived exertion in continuous and intermittent exercise with same average power output. *Eur. J. Clin. Invest.* 2:108–114, 1972.
8. Foster, C., M. Shrager, A. C. Snyder, and N. N. Thompson. Pacing strategy and athletic performance. *Sports Med.* 17:77–85, 1985.
9. Hampson, D. B., G. A. St Clair, M. I. Lambert, and T. D. Noakes. The influence of sensory cues on the perception of exertion during exercise and central regulation of exercise performance. *Sports Med.* 31:935–952, 2001.
10. Hampson, D. B., G. A. St Clair, M. I. Lambert, J. P. Dugas, E. V. Lambert, and T. D. Noakes. Effects of deception on perceived exertion during high-intensity run bouts. *Percept. Mot. Skills* 98: 1027–1038, 2004.
11. Kay, D., F. E. Marino, J. Cannon, A. St Clair Gibson, M. I. Lambert, and T. D. Noakes. Evidence for neuromuscular fatigue during high intensity cycling in warm humid conditions. *Eur. J. App. Physiol.* 84:115–121, 2001.
12. Lambert, E. V., A. St Clair Gibson, and T. D. Noakes. Complex system model of fatigue: integral control and defence of homeostasis during exercise in humans. *Br. J. Sports Med.* 39:52–62, 2005.
13. Lucia, A., J. Hoyos, A. Santalla, C. Earnest, and J. L. Chicharro. Tour de France versus Vuelta a Espana: which is harder? *Med. Sci. Sports Exerc.* 35:872–8, 2003.
14. Mihevic, P. M. Sensory cues for perceived exertion: a review. *Med. Sci. Sports Exerc.* 13:150–163, 1983.
15. Morgan, W. P. Psychological factors influencing perceived exertion. *Med. Sci. Sports* 5:97–103, 1973.
16. Nikolopoulos, V., M. J. Arkinstall, and J. A. Hawley. Pacing strategy in simulated cycle time-trials is based on perceived rather than actual distance. *J. Sci. Med. Sport* 4:212–219, 2001.
17. Noakes, T. D. Linear relationship between the perception of effort and the duration of constant load exercise that remains. *J. Appl. Physiol.* 96:1571–1573, 2004.
18. Noble, B. J., G. A. Borg, I. Jacobs, R. Ceci, and P. Kaiser. A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Med. Sci. Sports Exerc.* 15:523–528, 1983.
19. Pandolf, K. B. Differentiated ratings of perceived exertion during physical exercise. *Med. Sci. Sports Exerc.* 14:397–405, 1982.
20. Rauch, L., A. St Clair Gibson, E. V. Lambert, T. D. Noakes. A signaling role for muscle glycogen in the regulation of pace during prolonged exercise. *Br. J. Sports Med.* 39:34–38, 2005.
21. Rejeski, W. J., and P. M. Ribisl. Expected task duration and perceived effort: an attributional analysis. *J. Sport Psychol.* 2:227–236, 1980.
22. Schabort, E. J., W. G. Hopkins, and J. A. Hawley. Reproducibility of self-paced treadmill performance of trained endurance runners. *Int. J. Sports Med.* 19:48–51, 1998.
23. Schabort, E. J., J. A. Hawley, W. G. Hopkins, I. Mujika, and T. D. Noakes. A new reliable laboratory test of endurance performance for road cyclists. *Med. Sci. Sports Exerc.* 30:1744–1750, 1998.
24. St Clair Gibson, A., and T. D. Noakes. Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *Br. J. Sports Med.* 38:797-806, 2004.
25. St Clair Gibson, A., E. V. Lambert, M. I. Lambert, D. B. Hampson, and T. D. Noakes. Exercise and fatigue control mechanisms. *Int. Sports Med J.* 2(3):14 pp, 2001.
26. St Clair Gibson A., M. I. Lambert, and T. D. Noakes. Neural control of force output during maximal and submaximal exercise. *Sports Med.* 31:637–650, 2001.
27. Tatterson, A. J., A. G. Hahn, D. T. Martin, and M. A. Febarrio. Effects of heat stress on physiological responses and exercise performance in elite cyclists. *J. Sci. Med. Sport* 3:186–193, 2000.
28. Tucker, R., L. Rauch, Y. X. Harley, and T. D. Noakes. Impaired exercise performance in heat is associated with an anticipatory reduction in skeletal muscle recruitment. *Eur. J. Physiol.* 448:422–430, 2004.
29. Ulmer, H. V. Concept of an extracellular regulation of muscle metabolic rate during heavy exercise in humans by psychophysiological feedback. *Experientia* 52:416–420, 1996.
30. Zohar, D., and G. Spitz. Expected performance and perceived exertion in a prolonged physical task. *Percept. Mot. Skills* 52:975–984, 1981.



Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.