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Title: Longitudinal changes in response to a cycle-run field test of young male National "Talent identification" and Senior Elite Triathlon Squads

Running title: Response to a cycle-run field test: longitudinal analysis

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Abstract (275 words)

This study investigated the changes in cardiorespiratory response and running performance of 9 male "Talent Identification" (TID) and 6 male Senior Elite (SE) Spanish National Squad triathletes during a specific cycle-run test. The TID and SE triathletes (initial age 15.2±0.7 *vs.* 23.8±5.6 years, p=0.03; $\dot{V}O_2max$ 77.0±5.6 *vs.* 77.8±3.6 $mL \cdot kg^{-1} \cdot min^{-1}$, NS) underwent three tests through the competitive period and the preparatory period, respectively, of two consecutive seasons: Test 1 was an incremental cycle test to determine the ventilatory threshold (Th_{vent}); Test 2 (C-R) was 30 min constant load cycling at the Th_{vent} power output followed by a 3-km time trial run; and Test 3 (R) was an isolated 3-km time trial control run, in randomized counterbalanced order. In both seasons the time required to complete the C-R 3-km run was greater than for R in TID (11:09±00:24 *vs.* 10:45±00:16 min:ss, p< 0.01; and 10:24±00:22 *vs.* 10:04±00:14, p=0.006, for season 2005/06 and 2006/07, respectively) and SE (10:15±00:19 *vs.* 09:45±00:30, p< 0.001 and 09:51±00:26 *vs.* 09:46±00:06, p= 0.02 for season 2005/06 and 2006/07, respectively). Compared to the first season, completion of the time trial run was faster in the second season (6.6%, p< 0.01 and 6.4%, p< 0.01, for C-R and R test, respectively) only in TID. Changes in post-cycling run performance were accompanied by changes in pacing strategy but only slight or non-significant changes in the cardiorespiratory response. Thus, the negative effect of cycling on performance may persist, independently of the period, over two consecutive seasons in TID and SE triathletes; however improvements over time suggests that monitoring running pacing strategy after cycling may be a useful tool to control performance and training adaptations in TID.

Key words: transition, performance, maximum oxygen consumption, pacing

INTRODUCTION

The running component of male Elite draft-legal Olympic triathlon is becoming more important for overall race performance. Correlation coefficients of over 0.8 were observed between time to complete the run section in seconds and finishing position in male ITU World Cup, European Championship and World Championship competition, respectively, in 2002, 2005 and 2006 ((38); Vleck and Bürgi, personal communication). Overall triathlon performance is not only affected by running performance but also by performance during the cycle section. The higher the athlete is placed at the end of the cycle section, the greater the importance to his final position (29). Overall, the cycle to run transition (T2) is recognized as a crucial moment during competition and consequently it has been widely studied from both physiological and biomechanical points of view (see bibliography in reference 35).

Specific-T2 responses have been investigated using both laboratory and field-based tests. Running after cycling has been shown to elicit increases in oxygen consumption ($\dot{V}O_2$) (22), ventilation ($\dot{V}_E$) (18, 20) and heart rate (HR) (22) when compared to an isolated control run. The extent to which such increases occur, for both competition and controlled conditions, appears to be influenced by the athlete's ability (25, 27-28) and training status (5, 12, 27-28). It has been suggested that the assessment of "specific-T2 adaptation" over time, via examination of performance related indices (such as mean running speed or the metabolic cost of running) within the post-cycling running component of a "simulated T2" test, may prove beneficial to the battery of tests usually performed by young (potential Elite) triathletes (25). Moreover, in a later study Vleck et al. (36) suggested that cardiorespiratory variables may be a more sensitive gauge of specific-T2 adaptation than blood lactate concentration. They also highlighted the need of a T2 related test that is sensitive enough to detect changes in specific-T2 adaptive response over time. In addition to the potential ability of such test to distinguish between groups of athletes with different performance levels, this sensitivity would be important in the context of development of young triathletes.

Hitherto no investigations regarding the longitudinal changes in performance and cardiorespiratory response to running after cycling have been published. The extent of sensitivity to changes in the T2 adaptation over time between tests is also unknown and this may prove to be a useful tool in monitoring young athletes who are at the "talent identification" stage of their career. Therefore, the aim of this study was to assess the extent to which the cardiorespiratory response and running performance change over the course of two consecutive race seasons using a simulated T2 test in two different ability and maturation groups (34) of triathletes, *i.e.* the best Spanish under-16 year old males, and males within the Spanish Senior Elite National Squad.

METHODS

Experimental approach to the problem

We evaluated, in two different groups (see below), the specific-T2 cardiorespiratory response and running performance at the same period of two consecutive seasons (2005/06 and 2006/07). The experimental protocol involved a preliminary test to determine maximal oxygen uptake ($\dot{V}O_{2max}$) during cycling ergomentry and the individual ventilatory threshold (Th_{vent}), followed by two tests in randomized counterbalanced order: i) a field-based cycle-run test (C-R); and ii) an isolated control run (R), as described in detail below. The two different tests, C-R and R, were completed on an outdoor 400 m synthetic Tartan track. Running performance (time to complete the 3-km time trial) and cardiorespiratory response were measured during the C-R and R tests in order to evaluate both the changes over two consecutive seasons as well as the negative effect of cycling on subsequent running.

Participants

Two groups of male triathletes participated in the study (Table 1). The first group was composed of nine young triathletes who had been selected by the Spanish Triathlon Federation (FETRI) as being the best in the country. They had 18 ± 8 months of previous triathlon experience and had previously obtained a top ten finish in the under-16 category National Triathlon Championships one week before the start of the study. All of them were members of the FETRI *National Plan for Talent Identification* and are hereafter referred to as the TID group. Testing took place during a specific training camp in which athletes were living together, organized by FETRI, with all athletes following the same training schedules and the same diet. All triathletes passed a medical examination in the week prior to the experiments.

A second group of six Senior Elite (SE) Spanish National Squad triathletes took part in the study. The Senior Elites triathletes had [illegible] years of previous training background and participated regularly in international competitions. All were based at the High Performance Center in Madrid and followed similar diet and training schedules during the period of the study. The total number of athletes in the Senior National Squad fluctuated over the 2-year experiment, but at no time did our SE group account for less than 55% or for more than 65% of the complete male Spanish National Senior Squad. The SE triathletes were regularly assessed by the National team physician and had passed a complete medical examination at the beginning of the season (*i.e.* October).

In agreement with the guidelines of the 1975 Declaration of Helsinki, the study was approved by the Local University Ethics Committee. The participants were given both verbal and written information regarding the possible risks and benefits of the study. Signed informed consent was obtained from the senior triathletes and from the parents or legal guardians of the TID group before the start of the study.

Procedures

The TID triathletes carried out all the tests in Soria (Spain) during the competitive period (July). International racing commitments precluded the SE group from being tested at the equivalent period of the season and they were therefore tested (February of each respective year) in Madrid (Spain) during the final weeks of the preparatory phase. Both cities are at ~700 m altitude, the wind was calm, and the environmental conditions were both stable and similar in both seasons (Soria: 22 ± 2.4 ºC, 58 ± 3.8%, 702 ± 12 mmHg during season 2005/06 *vs.* 24 ± 2.1 ºC, 55 ± 5.3% and 705 ± 15 mmHg during season 2006/07. Madrid: 21.0 ± 3.2 ºC, 47 ± 2.1%, 699 ± 9 mmHg during season 2005/06 *vs.* 21.4 ± 3.0 ºC, 43 ± 3.4%, 701 ± 14 mmHg during season 2006/07). No significant intra- or inter- location differences in environmental conditions were noted at any point of the study.

All tests were performed at the same time of day, interspersed by one day of passive or active (swim only) rest. The subjects were constantly encouraged to give their maximum performance but they were not given any time or heart rate data during the tests.

Determination of cycling $\dot{V}O_{2max}$ and the ventilatory threshold

All the athletes performed an incremental test on a cycloergometer (Cardgirus® cycloergometer, G&G Innovación S.A., Spain) – which frame specifications were set by the athlete during his first test occasion to mimic his normal cycle position and maintained during the study. The test started with a 5 min warm-up period at 75 W·min^{-1}. Load was then increased by 25 W per minute until voluntary exhaustion. The athletes were asked to maintain a cadence from 70 to 90 rpm throughout the test. All tests fulfilled at least two of the following criteria (31): A respiratory exchange ratio (RER) higher than 1.10, a plateau in $\dot{V}O_2$ (corresponding to variation of less than 100 $ml \cdot min^{-1}$) despite an increase in exercise intensity, and a peak heart rate above 220 – age.

Breath by breath analysis of expired air was performed using a Jaeger Oxycon Mobile® (13, 32) gas analyzer (Erich Jaeger, Viasys Healthcare, Germany). The analyzer was calibrated immediately prior to testing according to the manufacturer´s instructions. The data were averaged every 30 seconds and the highest value at the highest load achieved was termed $\dot{V}O_{2max}$.

The Th_{vent} was estimated on data averaged every 10 seconds, using the V-slope method (2) by two experienced researchers working independently. As the coefficient of variation between said researchers' determinations of Th_{vent} was 1.8% and similar to that reported elsewhere (31), the intervention of a third researcher was not required.

The cycle-run test (C-R)

All subjects carried out a 10 min warm-up (involving 5 min cycling at less than 100 W, and 5 min running at a very easy but freely chosen intensity) prior to the test. The C-R test comprised 30 min of steady state cycling at the workload corresponding to Th_{vent} (16-18, 20) determined in Test 1 followed by a self-paced 3-km run (3-4). The subjects spent 34 ± 8 seconds, on average, to complete the cycle ergometer-to-track transition and were instructed to complete the running section of the trial as fast as possible. All subjects ingested 250 mL of cool water during the first 20 min of the cycling component of C-R. The portable gas analyzer

(Oxycon Mobile, Erich Jaeger, Viasys Healthcare, Germany) was then attached to the triathletes' back using a harness and $\dot{V}O_2$, CO_2 production ($\dot{V}CO_2$), $\dot{V}_E$, and respiratory frequency (f) were recorded and averaged over 10-second intervals. Ten seconds rather than the more customary thirty second averages for respiratory variables were chosen due to the necessity to obtain more than 1-2 data points per 400-m lap. HR was also recorded over 10 second intervals using a heart rate monitor (Polar 620i, Polar Electro, Kempele, Finland). All the variables, including speed (distance/time), were then expressed as means ± standard deviations (SD) for consecutive laps of the run track.

Isolated running test (R)

After a 10 min warm-up at a "very easy" self selected pace, the athletes were asked to perform a 3-km run time-trial (3-4) as fast as possible. During the R test, the cardiorespiratory responses of the athletes were measured as in the C-R test by means of the portable gas analyzer. The subjects' rating of perceived exertion (RPE) was recorded using the modified ten-point Borg scale (9) immediately after completion of both R and C-R test.

Statistical analyses

Differences in $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RER, f and HR between the running component of the C-R test and the R test were analyzed within the group via multivariate analysis (MANOVA) with season (season 2005/06 *vs.* season 2006/07), lap and condition (C-R *vs.* R) as independent factors. When significant differences were detected, pairwise comparisons with Bonferroni *Post hoc* adjustment were performed. Given the sample size (9 young and 6 Seniors triathletes) the statistical power achieved was >80%.

Performance, defined as the time required to complete the 3-km time trial run, was compared between tests within the season (C-R *vs.* R) as well as between seasons within the test (season 2005/06 *vs.* season 2006/07), using paired Student *t*-tests. For all the analyses, significance was set at $p < 0.05$. All calculations were made using SPSS v.18.0 software for Windows® (SPSS Worldwide Headquarters, Chicago, IL).

RESULTS

Both groups of athletes exhibited a cycling $\dot{V}O_{2max}$, and peak power output values (Table 1) comparable to those reported previously for members of the French National Squad (3, 19, 25-26). Between January 2005 and October 2007, the average pace during race competitions (draft-legal) was recorded in a minimum of 4 and a maximum of 8 races per subject (mean±SD = 5.5±1.1). All competitions for SE triathletes were performed over 10-km running sections and included ITU or ETU events. For TID triathletes, competitions included 3- or 5-km (as the Spanish Championships one week previous to the tests) running segments. Average mean speed was 3:25 and 3:35 min:ss per km for SE and TID group respectively.

Differences between C-R and R tests

In the TID triathletes, cycling had a negative effect on running performance in both seasons. The mean time taken to complete the running component of C-R was longer than that needed to complete the R test, by 3.5% (or 24 seconds, $p < 0.01$) and 3.3% (or 20 seconds, $p < 0.01$) in the 2005/06 and the 2006/07 seasons, respectively (Table 2, Fig. 1). The $\dot{V}_E$, the ratios of $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$, and the HR were also all higher ($p < 0.001$) in the C-R than in the R test, in both seasons (Table 2, Fig 2).

Table 3 shows the results of the SE triathletes. The cardiorespiratory response of the SE during the running component of C-R test did not differ from that exhibited within the isolated run, with the exception of HR. During the C-R run, the HR was lower ($p< 0.01$) in the first season and higher ($p= 0.03$) in the second season of the study (Table 3, Fig. 3). Within 400-m lap analyses also revealed significant differences in the HR between the C-R and the R test within the season, over the first 400 m (season 2005/06) or 800 meters (season 2006/07) of the run time-trial (Fig. 3). Moreover, time to complete the time trial run was also negatively affected (by 4.9% of total control run time, 30 seconds, $p< 0.001$; and 0.8%, 6 seconds, $p= 0.02$, in 2005/06 and 2006/07, respectively) by prior cycling, in both seasons (Table 3, Fig. 1).

Changes in cardiorespiratory response and performance over two consecutive seasons

Tables 2 and 3, and figures 2 and 3, respectively, show the evolution of the cardiorespiratory response to C-R over time, in TID and SE triathletes. Our younger athlete group exhibited an increase ($p< 0.001$) in mean $\dot{V}O_2$ from season 2005/06 to 2006/07 during the running component of the C-R test, but not during R. However, cycling $\dot{V}O_{2max}$ remained stable (no significant differences) between seasons (Table 1). The $\dot{V}_E/\dot{V}O_2$ ratio decreased ($p= 0.02$) in both tests, but $\dot{V}_E/\dot{V}CO_2$ was lower ($p< 0.001$) in the second season only during R (Table 2). Moreover, mean HR during the R test, but not during the C-R, was lower in season 2006/07 than in 2005/06 ($p< 0.001$). On the other hand, SE triathletes presented similar HR and $\dot{V}O_2$ over both seasons and tests (Table 3, Fig. 3).

While the TID triathletes took less time to complete the time trial run in season 2006/07 with respect to 2005/06, both the C-R (- 6.6%, 45 seconds, $p< 0.01$) and the R (- 6.4%, 41 seconds, $p= 0.01$) test (Table 2, Fig. 4), 3-km time trial times remained stable in the SE triathletes over both seasons and the two tests conditions (- 3.9% in C-R and + 0.3% in R) (Table 3, Fig. 3). Figure 2 shows that the differences between consecutive seasons in running speed within C-R were concentrated within the first 2,000 m of the run in the younger athletes. Within the R test condition, the differences occurred at the beginning (from 400 to 1200 m) and near the end (from 2400 m) of the trial. Analysis of consecutive 400-m laps did not reveal any significant difference between seasons in running speed in the SE triathletes either during C-R or R (Fig. 3). In both tests and groups, pacing was similar involving a quicker start in the first lap and a final increase in speed over the last 600 m of the run (Fig. 2 and 3). A 'U-shape' pacing pattern was more evident in the TID triathletes than in the SE. Individual subject analysis of running performance revealed that only one triathlete out of nine in the TID group did not improve his performance during C-R in the season 2006/07 over that observed in 2005/06 (Fig. 4, left panels). The SE group displayed higher intra-group variability and during the C-R test two out of six triathletes performed worse in 2006/07. Similarly, during the R test run half of the SE triathletes improved in the second season of the study while half took more time to complete the time trial than previously (Fig. 4 right panels).

DISCUSSION

Although almost a decade has elapsed since it was pointed out (29) that longitudinal examination of running performance indices during simulated T2 could prove a useful adjunct to training (6), particularly in the case of young triathletes (25, 29), the current study appears to be the first to have attempted to verify this. Our results demonstrate that the negative effect of cycling on subsequent running performance, as assessed by the time taken to complete a 3-km time trial run, was maintained over the two consecutive seasons of the study in both TID and SE triathletes. Nonetheless, running performance did improve in the second season but only in the young (potential Elite) triathletes – whereas SE triathletes presented a plateau in performance. The improvements, rather than being accompanied by changes in the cardiorespiratory response to the exercise task, appear to have been related to changes in pacing during the post-cycling run.

Effect of cycling on subsequent running

In the literature to date, the extent to which the cardiorespiratory response during the running component of a cycle-run transition was augmented over that of an isolated control run has been inversely related to the athlete´s ability level/experience and/or training status (5, 12, 27-28). Our data agree with previous studies as an increased ventilatory response was only observed in the TID triathletes. Indirect measures of respiratory efficiency (i. e. $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$) were also negatively affected by prior cycling (10-11, 16-17) in the latter group. Our subjects performed the post-cycling run at intensities (see % cycling VO_{2max} in tables 2 and 3) at which respiratory muscle fatigue has been demonstrated to occur (21). It has been suggested, however, that elite triathletes experience smaller changes in their cardiorespiratory mechanics during the post-cycling running component (16). Thus, the increase in the time taken to complete the time trial run during C-R test might be related to respiratory muscle fatigue (10-11) in the TID group, only. Surprisingly, time to complete the 3-km time trial run was impaired by prior cycle in both groups (Tables 2 – 3, Fig. 1). In part, this may be due to the novelty of the C-R test conditions to the SE triathletes leading to some "carry-over" of the pattern of cycling muscle recruitment to running, which is not seen during the more familiar race-like cycle conditions (8). Since cardiorespiratory response was similar in both tests, it is possible that the decrease in performance that was exhibited during the C-R test may be then related to the pacing that was adopted within it (15). Hausswirth et al. (15) demonstrated that pacing during the first kilometer at a speed 5% slower than the average pace of a 10-km control run results in improvements of 150 seconds in overall time. Our results show that both groups started the running component of the C-R test approximately 3% slower than the average speed at which they completed the isolated run. However while the SE triathletes adopted "J-shaped" running strategy, the younger triathletes adopted a "U-shaped" strategy (Fig. 2 and 3) (1) (with the latter becoming even more evident, after they had had a further year of experience, in 2006/07). Moreover, the cycling cadence and the RPE values collected at the end of both the C-R and R tests were near maximal in all cases (Tables 2 and 3). Therefore, in agreement with previous data (15), our results suggests that the ability to maintain post-cycling initial speed is an important contributor to final performance.

Biomechanical factors and changes in running pattern after cycling have also been proposed to affect running performance in triathlon (14, 18, 27-28). It is important to note that top-level triathletes preserve running kinematics after cycling but some of them suffer from an alteration in leg muscle activity (5-6). In our case, whatever the primary factor(s) determining the negative effect of cycling on subsequent running performance, the analysis of individual data depicted in Fig. 1 shows that cycling affected most of the subjects. Therefore, we suggest that the assessment of how effort/speed is distributed over the course of the time trial run section of the T2 simulation (15, 24), and any possible relationship between this and neuromuscular factors, may prove to be an interesting avenue of future research.

Changes in cardiorespiratory response and running performance over two consecutive seasons

In this study, performance under the C-R test conditions (i.e. 30 min cycling + 3-km time-trial run) only improved over time in the TID triathletes. We observed, however, that improvements in their post-cycling running performance were accompanied by only slight, non-significant, changes in cardiorespiratory parameters. Figure 2 shows that the speed attained during the first 2 kilometers during the time trial run of the C-R test improved in 2006/07 compared with 2005/06 without a change in the "U-shape" (1) or cadence during previous cycling. Therefore, it may be worth following up the adaptation to the first stages of a running "off the bike" via non-invasive methods such as an assessment of pacing during a field-based trial, particularly in the case of the younger and less experienced athletes. To date, from the eight triathletes who improved their performance during the C-R test, five are representing Spain at international level, which may be preliminary evidence of the sensitivity of our test to detect specific-T2 adaptations.

Assuming an improvement in running performance from the endurance base to the competitive-period of the season, it is plausible that the negative effect of cycling on consecutive running that was exhibited by the SE triathletes would have either decreased or disappeared by June. Due to calendar competitions and the proximity of the 2008 Olympics, the SE triathletes did not follow the same strategy and running training during the season 2006/07 and 2005/06. This could be one reason explaining why their running performance was affected by previous cycling differed between seasons. Nonetheless, SE triathletes displayed higher intra-group variability (Fig. 3). The relevance of these 3-km related results to their competitive performances over the 10-km run of the Olympic distance event, or the 5-km run of the Sprint event, for which a bid for inclusion in the Rio 2016 Olympic Games is currently underway, has not been established.

Limitations

In this study we defined performance as "time to complete the 3-km time trial run during either the C-R or the R test" and the assessment of reliability and validation of the test measures against competition performance is required. However, there is a strong evidence of the relation between post-cycling running performance and competition finishing position (24, 37-38) and our test is based on previous findings. First of all, we used a cycling section at the intensity corresponding to the Th_{vent} that lasted 30 min as this has been shown to produce a modified cardiorespiratory response from that observed during an isolated control run (10-11, 16-18, 20). Secondly, we chose a 3-km time-trial to assess running performance because said distance has been both implemented before in specific-T2 tests (3-4) and demonstrated to be sufficient to determine the possible effects of neuromuscular fatigue on performance (30). More importantly, the 3-km distance is the most commonly performed (both in competition and for the purposes of talent identification) by triathletes under-16 years of age in at least two of the eight highest ranked countries in the ITU qualification simulations for the 2012 Olympic Games (www.triathlon.org, accessed 11 March 2011). Finally, Laursen et al. (23) have previously obtained coefficients of variation for 1.5 and 5-km time trials run of 3.3% (ICC = 0.879) and 2.0% (ICC = 0.953). Similarly, Schabort et al. (33) have reported a coefficient of variation of 2.7% (ICC = 0.90) for self-paced time trial performance in endurance runners. Our TID group improved their C-R run times (in 8 triathletes out of 9), between the seasons 2005/06 and 2006/07, by more than 6% - more than expected for time trials over similar distances (23, 33). Their mean 3-km run speeds during the C-R tests and within race competitions over the course of the study also did not differ significantly. Overall, it appears likely that the results that we obtained for our TID group reflected a "real" change in their specific-T2 adaptation over time, rather than being due to random variation.

The study was also limited by a lack of collection of stride length and frequency data, which could have helped to explain the results. Nevertheless, the monitoring of performance indices during the post-cycling running component over time as a means of optimizing individual specific (performance and injury prevention-related) training intervention(s) (5, 7), may prove of major importance to young triathletes in particular (25). In this paper we have presented preliminary evidence that our test might be sensitive enough to detect specific-T2 adaptations, especially in potential Elite triathletes.

Conclusions

Our paper is the first one to report longitudinal changes in the cardiorespiratory response and running performance in a field-based cycle-run transition over the course of two consecutive seasons. While running performance after cycling remained stable in Senior Elite Spanish National Squad triathletes, it significantly improved in young triathletes enrolled in the Spanish National Talent Identification Plan. This improvement may have been related to differences in pacing rather than to changes in the cardiorespiratory response *per se*.

PRACTICAL APPLICATIONS

This work provides further insight into the evolution of performance during cycling-running succession. The existing academic literature and our results suggest that coaches should be aware of the importance of pacing strategy (especially at the beginning of the running component) on final performance. The incorporation of training sessions that are designed to automate pacing strategy into the athlete's training plan could be a useful means of improving their performance.

Although both the reliability and validity of our test need to be further evaluated, we have presented preliminary evidence that it may be sensitive to specific-T2 adaptation in the youngest triathletes. Once it has been more fully researched, our field-based test, likely more accessible to coaches than laboratory-based tests, may prove to be a useful addition to long-term triathlete development plans.

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Figure legends

Fig. 1. Change in time to complete the 3-km time trial run during season 2005/06 and 2006/07 in Talent Identification (left panels, n=9) and Senior Elite (right panels, n=6) triathletes. Data are normalized to R test. Dashed line represents the mean of the group. * Differences (p< 0.05) between tests.

Fig. 2. Lap by lap analysis of the cardiorespiratory response of Talent Identification triathletes (n=9) during R test (left panels) and C-R test (right panels) in season 2005/06 (close circles) and 2006/07 (open circles). Data represent the mean ± SEM. * Differences (p< 0.05) between seasons within the test. # Differences (p< 0.05) between tests within the season.

Fig. 3. Lap by lap analysis of the cardiorespiratory response of Senior Elite triathletes (n=6) during R test (left panels) and C-R test (right panels) in season 2005/06 (close circles) and 2006/07 (open circles). Data represent the mean ± SEM. No differences between seasons within the test were found. # Differences (p< 0.05) between tests within the season.

Fig. 4. Change in time to complete the 3-km time trial run during the C-R or R test in Talent Identification (left panels, n=9) and Senior Elite (right panels, n=6) triathletes. Data are normalized to season 2005/06. Dashed line represents the mean of the group. * Differences (p< 0.05) between seasons.

Table 1. Characteristics of the participants.

	Senior Elite (n=6)		Talent Identification(n=9)	
	Season 05/06	Season 06/07	Season 05/06	Season 06/07
Age (years)	24 ± 5.6	24.8 ± 5.6	15.2 ± 0.7*	16.2 ± 0.7*
Mass (kg)	71.2± 8.7	71.9 ± 6.8	60.2 ± 6.8	61.9 ± 6.6
Height (cm)	180.0 ± 8.8	180.2 ± 8.6	173.6 ± 6.4	174.0 ± 7.3
% fat	8.5 ± 0.6	8.3 ± 0.4	7.7 ± 0.6	7.9 ± 0.7
$\dot{V}O_{2max}$ ($mL\cdot kg^{-1}\cdot min^{-1}$)	77.8 ± 3.6	77.4 ± 4.6	77.0 ± 5.0	76.8 ± 5.9
HR_{max} ($beats\cdot min^{-1}$)	186 ± 3	184 ± 4	190 ± 2	188 ± 4
PO_{max} ($W\cdot kg^{-1}$)	5.7 ± 1.2	5.9 ± 0.8	5.1 ± 1.0*	5.3 ± 1.1*
Th_{vent} (%$\dot{V}O_{2max}$)	64.8 ± 3.1	66.1 ± 4.0	61.9 ± 5.2	63.1 ± 5.5
Th_{vent} ($W\cdot kg^{-1}$)	3.4 ± 0.8	3.6 ± 1.0	3.5 ± 1.1	3.6 ± 0.9

$\dot{V}O_{2max}$, cycling maximum oxygen uptake; HR_{max}, maximum heart rate; PO_{max}, maximum power output; Th_{vent}, ventilatory threshold. * Differences ($p< 0.05$) with Senior Elite triathletes.

Table 2. Cardiorespiratory response and running performance (means ± SD) in Talent Identification triathletes (n=9) during C-R and R test in season 2005/06 and 2006/07.

	Season 05/06		Season 06/07	
	C-R	R	C-R	R
$\dot{V}O_2$ (mL·min^{-1})	4222 ± 520	4350 ± 707	4549 ± 623 †	4088 ± 784
$\dot{V}O_2$ (% cycling VO_{2max})	89.9 ± 4.3	90.1 ± 3.9	92.1 ± 3.1 †	87.5 ± 6.1
$\dot{V}CO_2$ (mL·min^{-1})	3615 ± 298	3639 ± 604	3855 ± 468	3563 ± 518
$\dot{V}_E$ (L·min^{-1})	132.5 ± 16.8	127.2 ± 24.3*	139.5 ± 13.8	124.7 ± 23.8*
$\dot{V}_E/\dot{V}O_2$	35.0 ± 4.0	32.3 ± 2.8*	33.4 ± 1.9 †	30.6 ± 2.0 * †
$\dot{V}_E/\dot{V}CO_2$	35.6 ± 3.7	34.0 ± 3.3*	35.2 ± 1.4	30.7 ± 3.6 * †
f (resp·min^{-1})	57 ± 10	55 ± 11	60 ± 4	58 ± 9
HR (beats·min^{-1})	186 ± 8	181 ± [illegible]2*	184 ± 8	175 ± 10* †
RER	0.87 ± 0.04	0.85 ± 0.04*	0.84 ± 0.02	0.90 ± 0.07* †
RPE	9.5 ± 0.5	9.0 ± 0.5	9.4 ± 0.5	9.0 ± 0.5
Cadence (rpm)	91 ± 2	-	90 ± 2	-
Speed (km·h^{-1})	16.3 ±1.1 (3:43) [a]	16.7 ± 0.7* (3:35)	17.3 ± 0.7 † (3:28)	17.8 ± 0.4* † (3:21)
Time to complete run (mm:ss)	11:09±00:24	10:45±00:16*	10:24±00:22 †	10:04±00:14* †

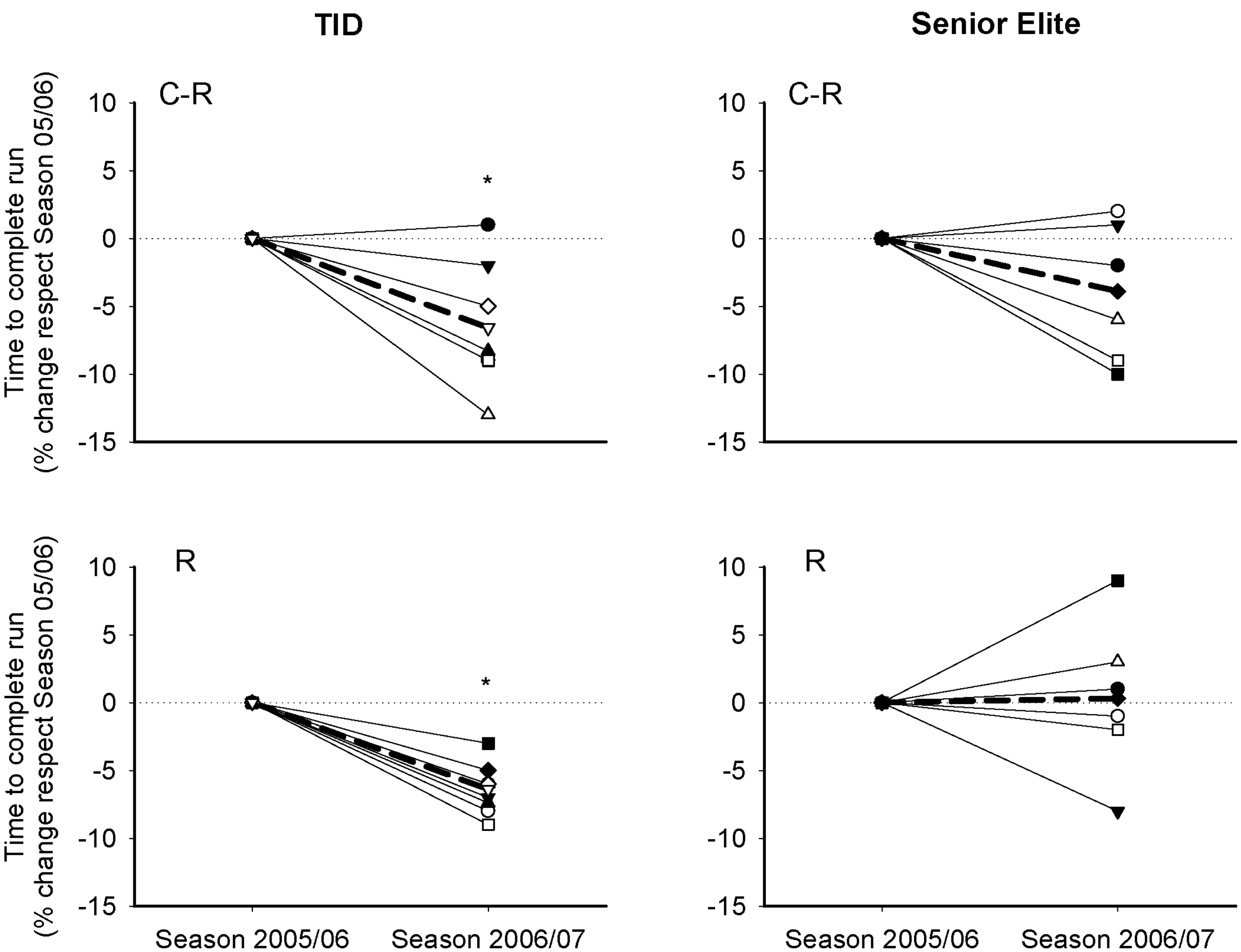
Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), tidal volume (V_T), breathing frequency (f), heart rate (HR), respiratory exchange ratio (RER), rating of perceived exertion (RPE). * Differences (p< 0.05) with C-R within the season. † Differences (p< 0.05) with season 2005/06 within the test. [a] Average speed/pace is shown between parentheses as min:ss·km^{-1}.

Table 3. Cardiorespiratory response (means ± SD) in Senior Elite triathletes (n=6) during C-R and R test in seasons 2005/06 and 2006/07.

	Season 2005/06		Season 2006/07	
	C-R	R	C-R	R
$\dot{V}O_2$ (mL·min^{-1})	4730 ± 340	4691 ± 914	4730 ± 307	4750 ± 333
$\dot{V}O_2$ (% cycling VO_{2max})	87.0 ± 3.6	84.5 ± 5.6	85.7 ± 4.5	88.2 ± 4.0
$\dot{V}CO_2$ (mL·min^{-1})	4119 ± 258	5145 ± 319	5186 ± 221 †	4055 ± 203 †
$\dot{V}_E$ (L·min^{-1})	139.8 ± 11.0	151.3 ± 18.7	155.6 ± 16.4	137.6 ± 6.8
$\dot{V}_E/\dot{V}O_2$	33.18 ± 1.34	37.59 ± 7.53	38.12 ± 4.28†	32.88 ± 2.43
$\dot{V}_E/\dot{V}CO_2$	32.97 ± 1.15	28.57 ± 1.93	29.24 ± 2.76 †	33.26 ± 2.44 †
f (resp·min^{-1})	55 ± 3	56 ± 7	56 ± 5	54 ± 4
HR (beats·min^{-1})	183 ± 7	17[illegible]8*	175 ± 9	178 ± 5*
RER	0.88 ± 0.03	1.03 ± 0.08	1.02 ± 0.05 †	0.87 ± 0.01 †
RPE	9.2 ± 0.4	9.0 ± 0.5	9.3 ± 0.5	9.0 ± 0.6
Cadence (rpm)	94 ± 3	-	95 ± 2	-
Speed (km·h^{-1})	17.5 ± 0.5 (3:25) [a]	18.5 ± 1.2* (3:15)	18.2 ± 0.8 (3:17)	18.4 ± 0.2* (3:15)
Time to complete run (mm:ss)	10:15±00:19	09:45±00:30*	09:51±00:26	09:46±00:06*

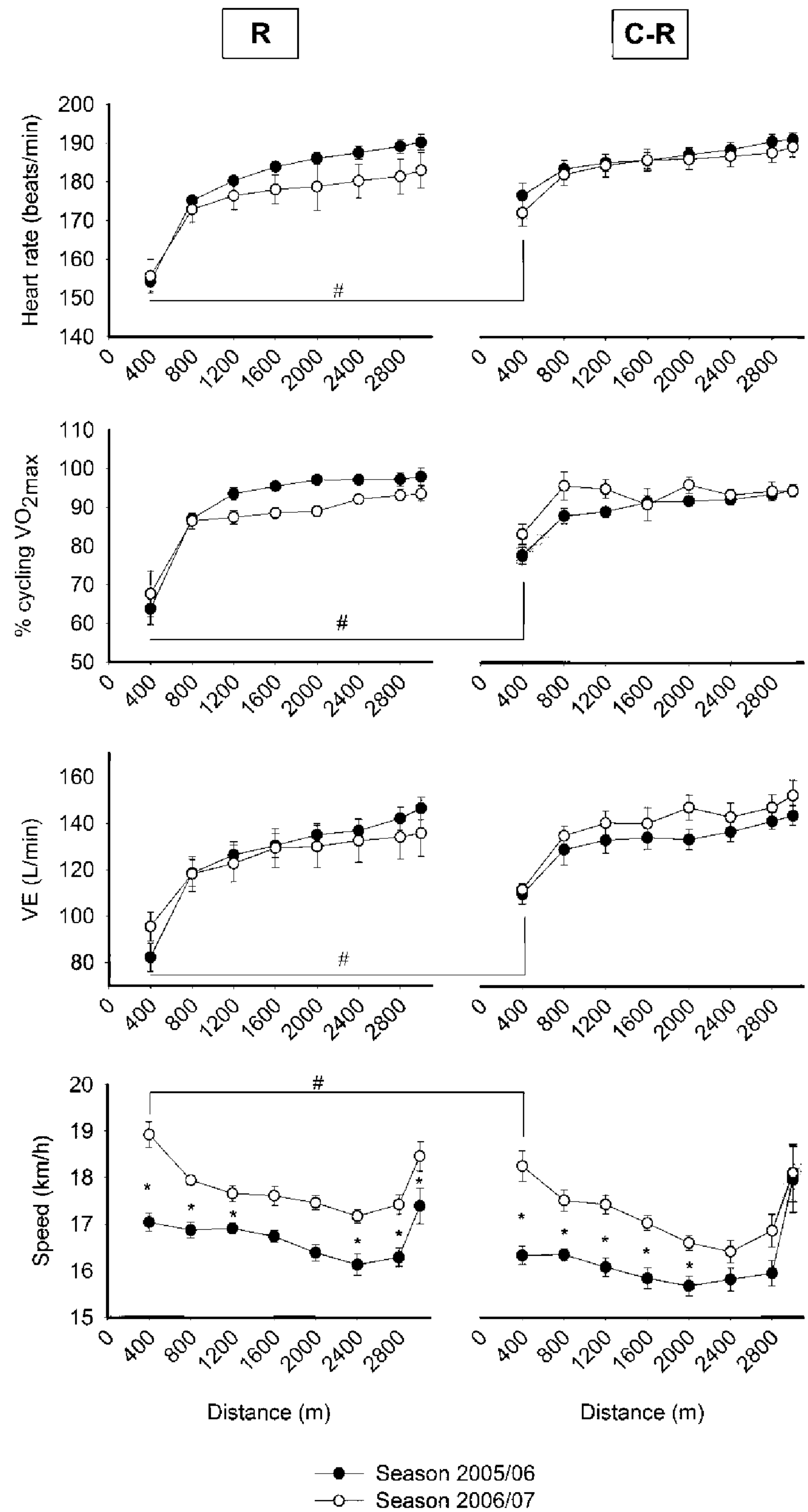
Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), tidal volume (V_T), breathing frequency (f), heart rate (HR), respiratory exchange ratio (RER), rating of perceived exertion (RPE). * Differences (p< 0.05) with C-R within the season. † Differences (p< 0.05) with season 2005/06 within the test. [a] Average speed/pace is shown between parentheses as min:ss·km^{-1}.

FIGURE 1



TID
Senior Elite
C-R
R
Time to complete run
(% change respect Season 05/06)
10
5
0
-5
-10
-15
*
Season 2005/06
Season 2006/07

FIGURE 2



R
C-R
Heart rate (beats/min)
% cycling VO2max
VE (L/min)
Speed (km/h)
#
*
Distance (m)
Distance (m)
Season 2005/06
Season 2006/07

FIGURE 3

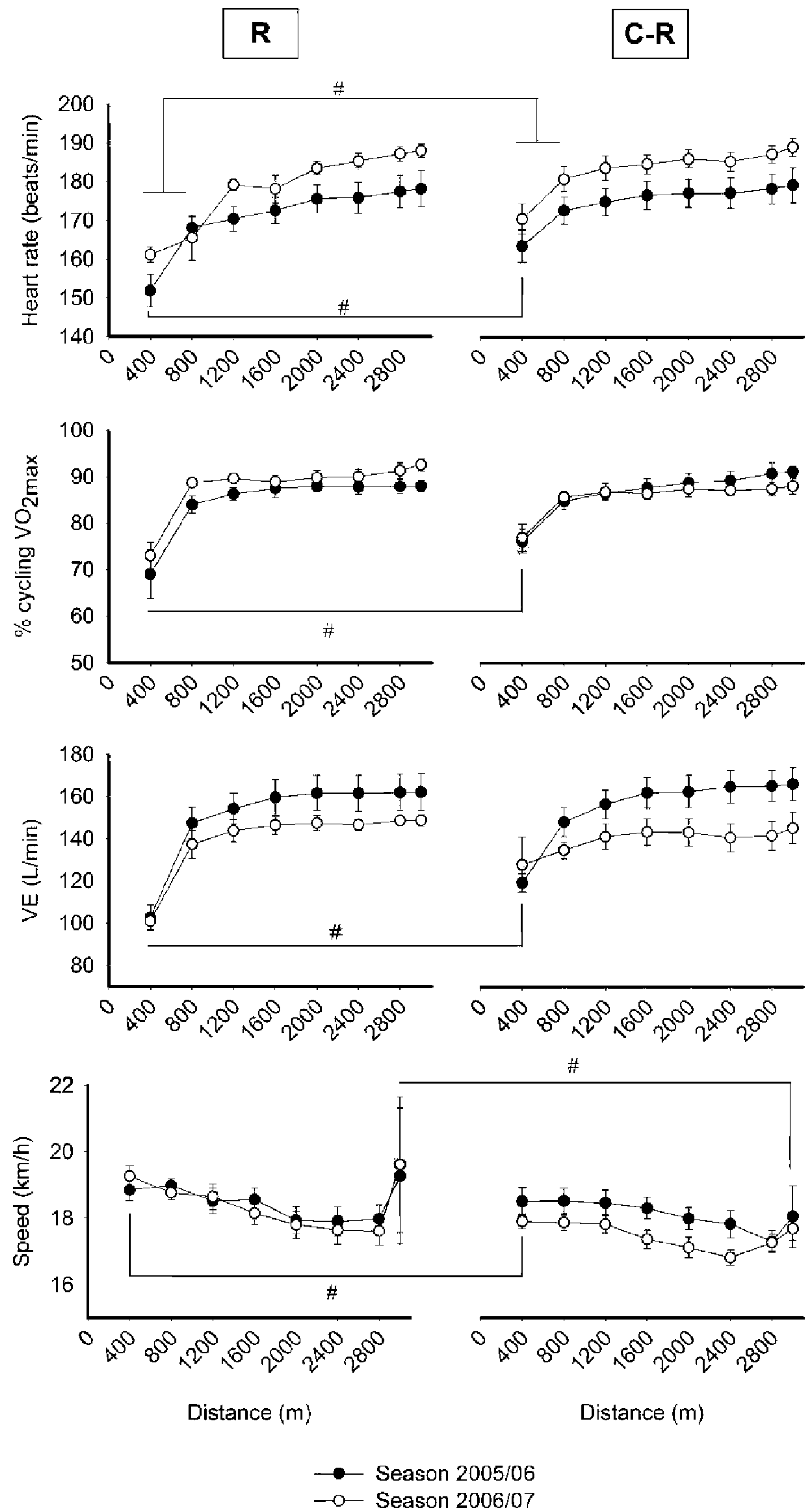
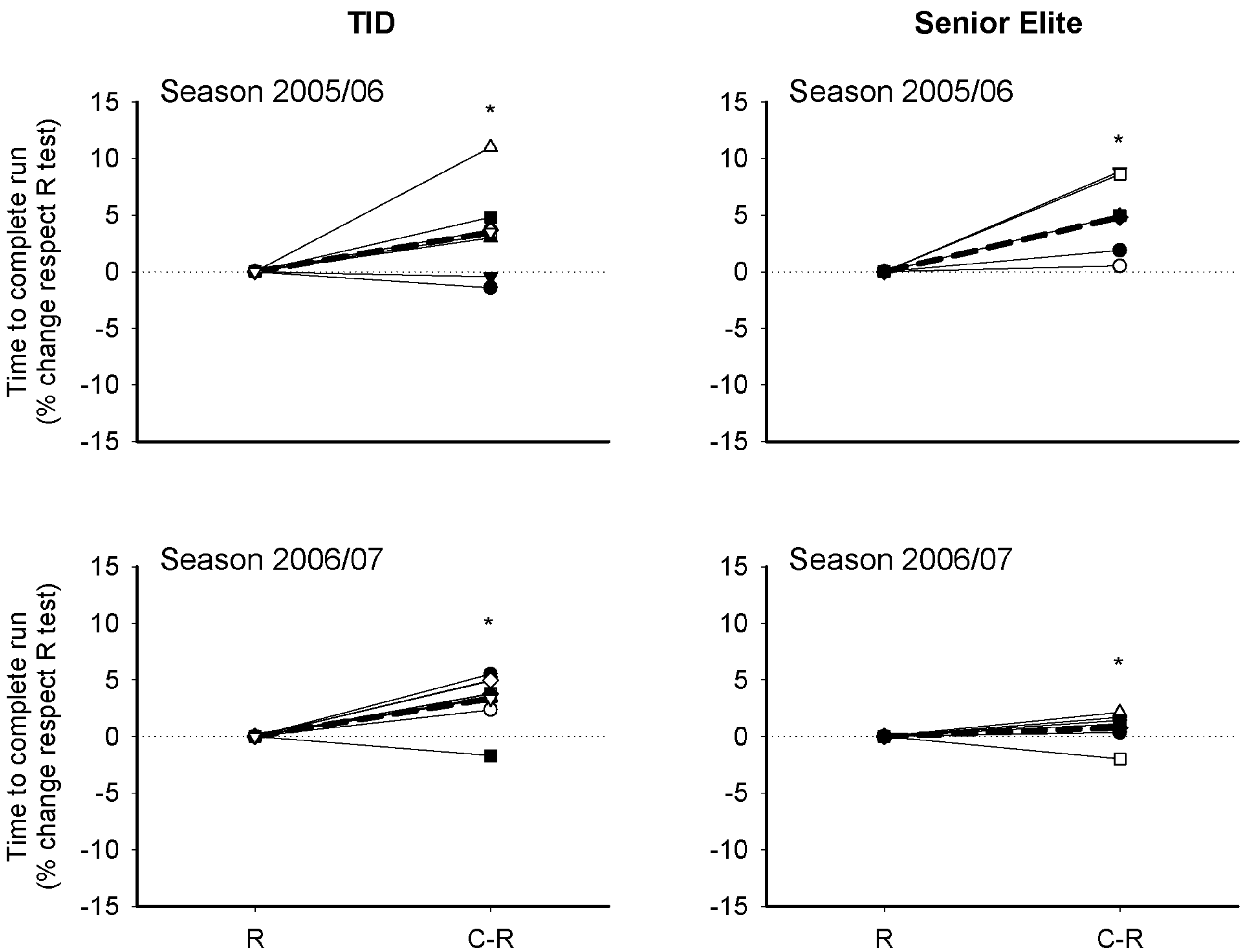

R
C-R
Heart rate (beats/min)
200
190
180
170
160
150
140
#
#
% cycling VO_2max
100
90
80
70
60
50
#
VE (L/min)
180
160
140
120
100
80
#
Speed (km/h)
22
20
18
16
#
#
0
400
800
1200
1600
2000
2400
2800
Distance (m)
Distance (m)
Season 2005/06
Season 2006/07

FIGURE 4


TID
Senior Elite
Season 2005/06
Season 2005/06
Season 2006/07
Season 2006/07
Time to complete run
(% change respect R test)
15
10
5
0
-5
-10
-15
*
R
C-R