Accepted Manuscript

Effects of deceptive running speed on physiology, perceptual responses, and performance during sprint-distance triathlon

Daniel Taylor, Mark.F. Smith

PII: S0031-9384(14)00257-1
DOI: doi: 10.1016/j.physbeh.2014.05.002
Reference: PHB 10417

To appear in: *Physiology & Behavior*

Received date: 18 September 2013
Revised date: 20 February 2014
Accepted date: 2 May 2014

Effects of deceptive running speed on physiology, perceptual responses, and performance during sprint-distance triathlon.

Daniel Taylor[1] and Mark. F. Smith[1]

[1]School of Sport and Exercise Science, University of Lincoln, Lincoln, LN6 7TS, United Kingdom.

Corresponding author details;

Daniel Taylor

School of Sport and Exercise Science,

University of Lincoln,

Lincoln,

LN6 7TS,

United Kingdom.

Phone: (+44) 01522 886845

E-mail: dtaylor@lincoln.ac.uk

Abstract

Objective: This study examined the effects of speed deception on performance, physiological and perceptual responses, and pacing during sprint-distance triathlon running. Methods: Eight competitive triathletes completed three simulated sprint-distance triathlons (0.75 km swim, 20 km bike, 5 km run) in a randomised order, with swimming and cycling sections replicating baseline triathlon performance. During the first 1.66 km of the run participants maintained an imposed speed, completing the remaining 3.33 km as quickly as possible. Although participants were informed that initially prescribed running speed would reflect baseline performance, this was true during only one trial ($\text{Tri-Run}_{100\%}$). As such, other trials were either 3% faster ($\text{Tri-Run}_{103\%}$), or 3% slower ($\text{Tri-Run}_{97\%}$) than baseline during this initial period. Results: Performance during $\text{Tri-Run}_{103\%}$ (1346 ± 108 s) was likely faster than $\text{Tri-Run}_{97\%}$ (1371 ± 108 s), and possibly faster than $\text{Tri-Run}_{100\%}$ (1360 ± 125 s), with these differences likely to be competitively meaningful. The first 1.66 km of $\text{Tri-Run}_{103\%}$ induced greater physiological strain compared to other conditions, whilst perceptual responses were not significantly different between trials. Conclusions: It appears that even during 'all-out' triathlon running, athletes maintain some form of 'reserve' capacity which can be accessed by deception. This suggests that expectations and beliefs have a practically meaningful effect on pacing and performance during triathlon, although it is apparent that an individual's conscious intentions are secondary to the brains sensitivity to potentially harmful levels of physiological and perceptual strain.

Keywords: Perceived exertion, affect, multisport, teleoanticipation, central governor, deception

1. Introduction

A key aspect of successful endurance performance is the adoption of an appropriate and effective pacing strategy, whereby an individual's desire to achieve the fastest possible finishing time is balanced against the avoidance of a meaningful slowdown, premature exhaustion or potentially damaging homeostatic disturbances [1-3]. This pacing strategy is the result of an ongoing 'internal negotiation' process within the brain which relies on an experientially developed 'template' of how work-rate, effort and perceived exertion levels are expected to develop throughout the event [2,4]. As the primary function of this process is believed to be protection from harm, it is thought to incorporate a substantial 'threshold' or 'reserve' capacity so that an athlete's absolute physiological capacity is never fully reached [5-9]. Allowing athletes to safely sustain work-rates beyond this protective limit (i.e. without succumbing to physiological damage or harm) therefore provides a potential means with which to improve endurance performance [7].

A number of studies have attempted to illicit performance improvements in this manner by providing deceptive feedback to manipulate athletes' expectations or beliefs [7,8,10-13]. Micklewright and colleagues [7] examined the effects of providing deceptive feedback during the first two of three 20 km cycling time trials, which conditioned participants to believe they could sustain speeds 5% higher than actual values. The provision of accurate feedback during the third time trial had no significant effect on overall performance time, speed or power output, although a far more aggressive pacing strategy was adopted by participants during the first 5 km. Whilst this suggests that manipulated performance beliefs can influence an individual's pace regulation, it also illustrates the brain's limited tolerance to mismatches between actual and anticipated levels of effort or exertion. Thus, it seems that any access to the physiological 'reserve' has a relatively robust upper limit, which is always kept below an individual's true task-specific maximum capacity [14]. Aggressive work-rates which exceed this limit are therefore unlikely to be sustained for long enough to benefit overall performance, regardless of an individual's desire to do so. As such, Stone et al. [8] have demonstrated significant improvements in time trial performance when exposing cyclists to a less aggressive feedback deception than that utilised by Micklewright et al. [7]. During this study participants competed against what they believed to be their previous baseline time trial performance, unaware that this actually corresponded to 102% of their mean baseline power output. These findings underline the limited tolerance of athletes to performance-enhancing levels of deception, with the authors suggesting that the magnitude of this limit may closely relate to values of typical athlete variability between performances. However, whilst the significant performance improvements observed by Stone et al. [8] were also deemed to be competitively meaningful, the 4 km cycling time trial is a relatively short single-discipline endurance event (~ 6 mins). Such findings may therefore have limited relevance to longer distance multi-disciplinary endurance events such as triathlon (~1 hr to 17hrs for sprint-distance to Ironman, respectively), due to the relative differences in exercise intensity and physiological stress imposed on athletes [15,16]. Furthermore, there is considered to be more uncertainty regarding the endpoint and appropriateness of pacing during longer-distance endurance events which, in turn, leads athletes to maintain a greater 'reserve' capacity [9]. The triathlon may therefore provide greater opportunity for deception to improve performance as a result of access to the physiological 'reserve', compared to those shorter event distances studied previously.

Stone and colleagues [8] have also acknowledged the limited scope of using perceived exertion as the sole overarching measure of an individual's perception of exercise intensity. As such, they suggest that other cognitive processes, such as affective response, warrant examination during self-paced performance tasks. Indeed, the recent findings of Renfree et al. [17] suggest affect may be more important than perceived exertion in the regulation and tolerance of aggressive pacing strategies during endurance performance. Furthermore, it has long been proposed that to better understand pace regulation, perceived exertion should not be considered as one global measure, rather, each of those afferent signals considered influential during performance (e.g. muscular and thermal strain, metabolic flux, breathlessness) should be examined as individual mediators which form part of the centrally integrated pacing process [18,19].

To our knowledge, the effect of belief manipulation on performance, physiological and perceptual responses, and pacing, is yet to be examined during self-paced multi-disciplinary endurance events such as triathlon, whereby residual fatigue across consecutive disciplines can have a unique and detrimental effect on pace regulation [20]. This is despite a number of studies highlighting the importance of pacing strategies adopted by triathletes, particularly during the running phase of competition which has a greater influence on success compared to the preceding swim and cycle [21-23]. Furthermore, as it is suggested that triathletes may optimise running performance by avoiding the aggressive pacing strategies commonly adopted during competition [22,23], it is of interest to examine whether such pacing changes and subsequent performance benefits can be elicited using deceptive methods. Therefore, the purpose of this study was to examine whether deceptively manipulating speed during the initial section of a sprint-distance triathlon run influenced overall performance, physiological and perceptual responses, and the subsequent pacing strategy adopted.

2. Methods

2.1. Participants

Eight non-elite, competitive triathletes (1 female) volunteered to participate in this study with a mean (± SD) age, body mass, stature and maximum oxygen uptake ($\dot{V}O_{2max}$) of 40.5 ± 3.8 yrs, 76.4 ± 12.2 kg, 1.75 ± 0.08 m and 53.5 ± 6.7 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. Participants had been competing in triathlons for at least 12 months and were in their off season at the time of the study. The groups training during the study period averaged 1.7 $h \cdot wk^{-1}$ swimming, 2.3 $h \cdot wk^{-1}$ cycling, 2.2 $h \cdot wk^{-1}$ running and 1.3 $h \cdot wk^{-1}$ strength and conditioning. Prior to any data collection a medical history questionnaire and written, informed consent were obtained from all participants. At this preliminary stage participants were misinformed that the purpose of the study was to examine the reliability and validity of simulated sprint-distance triathlon performance, and associated physiological and perceptual responses. In accordance with previous deceptive research [8,10] all participants were fully debriefed about the true nature of the study upon completion of all trials. All study procedures were approved by the institutional ethics committee. Throughout the study period participants were allowed to maintain their usual training regime but were instructed to avoid training in the 24 h prior to each trial. As such, training was recorded daily by participants to ensure consistency across trials. Furthermore, participants replicated dietary and fluid intake in the 24 h period preceding each trial, using a standardized recording sheet and serving as their own control.

2.2. Procedure and apparatus

Each participant completed six testing sessions in total, the first of which was an incremental treadmill assessment to determine $\dot{V}O_{2peak}$. This began with a 5 min warm-up at 7 $km \cdot h^{-1}$, with speed subsequently increasing by 1 $km \cdot h^{-1}$ each minute until volitional exhaustion. The methods outlined by Sultana et al. [24] were subsequently used to establish $\dot{V}O_{2peak}$. During their second session participants completed a field-based sprint-distance triathlon (750 m swim, 20 km cycle and 5 km run) to establish baseline performance within each discipline, utilising the same course and measurement methods as described previously [20]. The third preliminary session familiarised participants with the protocol and measurement methods of subsequent experimental trials, with each individual completing a practice simulated triathlon session (750 m swim, 10 km bike, 2.5 km run). These reduced cycle and run distances were implemented in order to minimise the physiological strain of the familiarisation period. Indeed, we have previously demonstrated that incorporating reduced distances during simulated triathlon provides adequate familiarisation to athletes [25], particularly if a 'race-pace' effort over the sprint-distance format has been completed in the preliminary testing period. During the familiarisation trial, swim pace, cycling power output (and cadence), and speed during the first 1.66 km of the run were fixed to replicate average equivalents measured during field-based triathlon performance. For the remainder of the run participants were encouraged to utilise the treadmill controls to become accustomed with the frequent selection and adjustment of their running speed, in order to more closely replicate the dynamic pacing of competitive field-based performance. This trial also familiarised participants with the methods and scheduling of perceptual and physiological measurement that would be adopted during subsequent experimental trials.

Following preliminary testing participants completed three separate simulated sprint-distance triathlons (0.75 km swim, 20 km bike, 5 km run). These trials were performed at the same time of day and were separated by a minimum of 3 days. The duration and work rate imposed during swimming and cycling was again fixed for each participant to replicate their baseline triathlon performance, with the time taken to complete first and second transitions (225 ± 20 s and 204 ± 37 s, respectively) comparable to previous studies of simulated triathlon performance [2,25,26]. At the end of the second transition of each trial, participants mounted the treadmill and were instructed to maintain the prescribed running speed for the first 1.66 km, having been misinformed that this speed would always equate to their baseline triathlon performance. On reaching 1.66 km participants were instructed to complete the remainder of each trial in as short a time as possible, as during competition. As such, participants were free to adjust their pace as often as required, with a single push of the treadmill controls equating to a 0.1 $km \cdot h^{-1}$ increase or decrease in belt speed. The only feedback given to participants throughout each run was to confirm distance completed. This was provided at 1 km intervals and also following the measurement of physiological and perceptual responses at 1.66 and 3.33 km. Based on participant feedback during familiarisation, the frequency of distance feedback was increased to 200 m during the final kilometre of each run. *Ad libitum* intake of fluid and carbohydrate gel was allowed during the cycling leg of the first experimental triathlon, with the volume and timing of this intake replicated during the second and third trials.

Initially imposed treadmill speed was an accurate reflection of baseline performance during only one trial ($Tri\text{-}Run_{100\%}$). During the other two trials initial treadmill speed was either 3% faster ($Tri\text{-}Run_{103\%}$), or 3% slower ($Tri\text{-}Run_{97\%}$) than the mean running speed of baseline triathlon performance. Participants completed each deception condition in a randomised order to minimise the effects of familiarisation, training and fatigue between trials. The magnitude of deception selected only marginally exceeds the 95% confidence interval (CI) for the coefficient of variation (CV) we have previously established for run performance during simulated sprint-distance triathlon (CV = 1.3%; 95% CI = 0.8 – 2.9%) [25]. This would therefore allow a worthwhile change in performance to be imposed, whilst also minimising the likelihood of participants noticing the manipulation of running speed between trials. The imposition of speed during the first 1.66 km of the run was deemed appropriate as this period appears to be particularly important in the evolution of pacing strategy during sprint-distance triathlon [20] and standalone 5 km road races [27]. Furthermore, the time required to complete this initial distance corresponded to the 6-8 minute period of specific physiological adaptation experienced by competitive triathletes during the cycle to run transition [28].

During all laboratory trials, swimming was performed in a temperature-controlled flume (Fastlane, Endless Pools, UK; water temperature ~23.4°C), with all cycling and running completed in an adjacent environmentally controlled room (temperature ~18°C; relative humidity ~48%). Electric fans provided a consistent level of additional air ventilation throughout all trials. Cycling was completed on an electromagnetically braked ergometer (SRM; Jülich, Welldorf, Germany) fitted with participants' own pedals and adjusted to replicate the set up of each athlete's own bicycle. Running was performed on a motorised treadmill at a fixed gradient of 1% (HPCosmos, Traunstein, Germany). All breath-by-breath measurements of oxygen uptake ($\dot{V}O_2$), respiratory exchange ratio (RER) and ventilation ($\dot{V}_E$) were recorded continuously using an automated, online metabolic cart (Cortex Metalyzer, Leipzig, Germany). The gas analyser of this system was calibrated prior to each trial using ambient air and reference gases of known concentration (16.07% O_2, 4.05% CO_2), whilst volume was calibrated using a 3 L gas syringe. Heart rate (HR) was measured with a Polar Heart Rate Monitor (RS_{400}, Polar Electro Kempele, Finland) which was integrated with the Cortex system to continuously record data.

2.2.1. Physiological responses

Before each triathlon trial participants fitted a transmitter belt under their triathlon suit to allow heart rate to be recorded. At the end of the cycle-to-run transition participants were equipped with the online gas analyser. Average values for all respiratory and heart rate data were obtained for the final 500 m of each 1.66 km run section completed (1.16-1.66, 2.73-3.33 and 4.5-5 km). Fingertip capillary blood was analysed for blood lactate concentration ($[BLa^-]$; Lactate Pro, Kodak, Japan) at 1.66 and 5 km.

2.2.2. Perceptual responses

Verbal ratings of perceived muscular pain, effort, breathlessness, affect and thermal discomfort were obtained from participants, in that order, at 1.66, 3.33 and 5 km of each triathlon run. Borg CR-10 scales [29] were used to rate muscular pain, breathlessness and thermal discomfort. Rating descriptors were adapted for each scale accordingly (0 = no muscular pain, breathlessness or thermal discomfort; 10 = previously experienced worst muscular pain, breathlessness or thermal discomfort) and participants were familiarised with how to rate their sensations during preliminary trials, as explained by Jameson and Ring [19]. The 11-point Feeling Scale was used to quantify the type and level of affect (pleasure or displeasure) experienced by participants (+5 = very good; 0 = neutral; -5 = very bad). As outlined by Astorino et al. [30], participant understanding of this scale was facilitated by the standardised explanatory script developed by Hardy and Rejeski [31]. To measure perceived effort a modified 6-20 Borg scale [32] was used, with participants instructed to rate only the sensations of psychological effort they were experiencing, ignoring any physical sensations they may be aware of. Using a similar modification of the Borg 6-20 scale, Swart et al. [33] have established that athletes are able to clearly distinguish between psychological effort and physiological sensations when providing such perceptual ratings in this manner.

2.3. Statistical analysis

Data were analysed using SPSS for Windows (Version 19, SPSS Inc., Chicago, USA). A one-way repeated-measures analysis of variance was used to examine differences in run and total triathlon completion times between trials. Based on the recommendations of Batterham &

Hopkins [34] analysis of running and triathlon performance also included magnitude-based inferences, whereby the chance of practically beneficial, trivial or harmful differences between conditions was calculated using a published spreadsheet [35]. This required values for the smallest worthwhile change in run performance during simulated sprint-distance triathlon, which has been established for non-elite, competitive triathletes as ~0.6% [25].

A series of two-way within-subjects (run type x run distance) ANOVA's were conducted to analyse main effects of run condition and distance completed using 1.66km split times, mean 1.66km section speeds, [BLa$^-$], HR, $\dot{V}O_2$, $\dot{V}_E$, RER, perceived muscular pain, effort, breathlessness, affect and thermal discomfort as dependent variables. Repeated measures ANOVA's were used to identify changes in these variables during the course of each trial. If the Mauchly test indicated a violation of sphericity then analysis of variance was adjusted using the Greenhouse–Geisser correction factor to reduce the likelihood of type I error. Where appropriate, Bonferroni-adjusted post-hoc tests were used to identify specific differences within and between running trials.

Pearson's product-moment correlations were used to determine the strength of relationships between performance, physiological and perceptual data during each running trial. Repeated measures ANOVA examined any differences in these *r* coefficients between each running condition. As rationalised by Vescovi and McGuigan [36], threshold values for *r* coefficients were set at <0.7 (low or weak), 0.7 – 0.89 (moderate), and >0.9 (high or strong). For all statistical procedures the level of significance was set at $p<0.05$ and adjusted accordingly. All data are expressed as means ± standard deviations.

3. Results

3.1. Performance measures

No statistically significant differences were observed between trials in the time taken to complete any of the individual triathlon disciplines, including the run ($P>0.05$). However, there was a trend for the fastest run (and overall triathlon) time to be achieved during the Tri-

$Run_{103\%}$ condition, and the slowest run (and overall triathlon) time during the $Tri\text{-}Run_{97\%}$ condition (Table 1).

Table 1 Mean ± SD overall and isolated performance times during each triathlon trial (n = 8).

	Swim (s)	Cycling (s)	Run (s)	Overall (s)
Tri-Run $_{97\%}$	805 ± 106	2320 ± 157	1371 ± 108	4496 ± 309
Tri-Run $_{100\%}$	805 ± 106	2319 ± 157	1360 ± 125	4484 ± 314
Tri-Run $_{103\%}$	805 ± 106	2319 ± 156	1346 ± 108	4471 ± 298

With regard to the practical significance of any differences in running performance, the magnitude-based chances that the true effect was a faster/trivial/slower time for $Tri\text{-}Run_{103\%}$ were 77:15:8% (*likely faster*) versus $Tri\text{-}Run_{97\%}$, and 59:28:12% (*possibly faster*) versus $Tri\text{-}Run_{100\%}$. The chances that the true effect was a faster/trivial/slower times for $Tri\text{-}Run_{100\%}$ versus $Tri\text{-}Run_{97\%}$ were 64:31:5% (*possibly faster*). Repeated-measures ANOVA revealed a significant main effect on cumulative 1.66km split times for deception condition ($F_{1.005,7.038}$ = 1016.9, P<0.001, η_p^2 = .99) and run distance ($F_{2.0,14.0}$ = 9.0, P<0.01, η_p^2 = .56), but no deception condition × distance interaction ($F_{1.228,8.596}$ = 0.3, P>0.05, η_p^2 = .04). Post-hoc analysis revealed systematic differences in split times at 1.66km between all deception conditions (424 ± 27, 440 ± 32 and 454 ± 32 s for $Tri\text{-}Run_{103\%}$, $Tri\text{-}Run_{100\%}$ and $Tri\text{-}Run_{97\%}$, respectively, P ranging from 0.001 to 0.017; Fig. 1). Differences in cumulative split times were also evident at 3.33 km between $Tri\text{-}Run_{103\%}$ and $Tri\text{-}Run_{97\%}$ (889 ± 68 and 909 ± 65 s, respectively, P<0.05). There were no statistically significant differences observed between trials in relation to isolated split times for the second and third 1.66 km sections (P>0.05). Furthermore, a sustained reduction in speed during $Tri\text{-}Run_{103\%}$ (P<0.05) was the only significant pacing change observed between successive 1.66 km sections of all trials, although an increase in running speed was apparent during the final 400 m of all trials (1.8, 2.7 and 2.3% for $Tri\text{-}Run_{97\%}$ $Tri\text{-}Run_{100\%}$ and $Tri\text{-}Run_{103\%}$, respectively; Fig. 2).

3.2. Physiological measures

No significant global effects of deception condition were found on HR, $\dot{V}O_2$, $\dot{V}_E$ or RER (P>0.05). However, significant distance effects were revealed for HR ($F_{2.0,14.0}$ = 5.1, P<0.05, η_p^2 = .42) and RER ($F_{2.0,14.0}$ = 26.2, P<0.001, η_p^2 = .79), whilst a significant condition × distance interaction was found for $\dot{V}O_2$ ($F_{4.0,28.0}$ = 4.9, P<0.005, η_p^2 = .41). Profiles of physiological measures over the course of each running trial, including post-hoc analysis outcomes, are presented in Fig. 3. As such, significant condition effects were evident during the first 1.66 km for HR, $\dot{V}O_2$, $\dot{V}_E$, RER and [BLa^-] (P<0.05). Pearson's product-moment correlations between physiological measures and distance were similarly weak during all trials, with RER demonstrating the strongest association during Tri-Run$_{100\%}$ (r = -0.63, P<0.01) and Tri-Run$_{103\%}$, (r = -0.48, P<0.05). The collation of data from all trials further reinforced RER as the only significant correlate with distance covered (r = -0.44, P<0.01).

3.3. Perceptual measures

Profiles of perceptual measures during each running trial, including post-hoc analysis outcomes, are presented in Fig. 4. No significant main condition effects or condition × distance interactions were found for any perceptual measure (P>0.05). However, significant distance effects were revealed for RPE ($F_{2.0,14.0}$ = 34.4, P<0.001, η_p^2 = .83), affect ($F_{2.0,14.0}$ = 30.6, P<0.001, η_p^2 = .81), muscular pain ($F_{2.0,14.0}$ = 23.5, P<0.001, η_p^2 = .80), breathlessness ($F_{2.0,14.0}$ = 34.4, P<0.001, η_p^2 = .83) and thermal discomfort ($F_{2.0,14.0}$ = 11.9, P<0.001, η_p^2 = .63). Pearson's product-moment correlations between perceptual measures and distance were significant during Tri-Run$_{97\%}$ for RPE (r = 0.68, P<0.01), muscular pain (r = 0.45, P<0.05), breathlessness (r = 0.71, P<0.01) and thermal discomfort (r = 0.48, P<0.05). During Tri-Run$_{100\%}$ only breathlessness (r = 0.50, P<0.05) and thermal discomfort (r = 0.46, P<0.05) were associated with distance, with no associations evident during Tri-Run$_{103\%}$ (r = 0.12 to 0.31). Collated data from all trials indicated weak but significant associations between all perceptual measures and distance covered (r = 0.26 to 0.42, P = 0.001 to 0.029).

3.4. Relationships between performance, perceptual and physiological measures

Repeated-measures ANOVA showed that the *r* coefficients between affect and other measures was the only significant difference when comparing running conditions, specifically Tri-Run$_{97\%}$ and Tri-Run$_{103\%}$, ($P<0.05$). The strength of relationships between running speed and perceptual measures were similarly weak during each trial (*r* ranging from 0.09 to 0.30, 0.07 to 0.42 and -0.02 to 0.24 for Tri-Run$_{97\%}$, Tri-Run$_{100\%}$ and Tri-Run$_{103\%}$, respectively). Likewise, there were comparably weak associations between physiological and perceptual measures during each trial (*r* ranging from 0.00 to 0.43, 0.00 to 0.52 and -0.01 to 0.47 for Tri-Run$_{97\%}$, Tri-Run$_{100\%}$ and Tri-Run$_{103\%}$, respectively). Generally, physiological measures demonstrated stronger relationships with running speed compared to perceptual responses, particularly in the case of $\dot{V}O_2$ (r = 0.49 to 0.61) and $\dot{V}_E$ (r = 0.78 to 0.80). A number of separate perceptual measures were found to be moderately or strongly associated with each other over the course of each run, with perceived effort and breathlessness in particular demonstrating a consistently strong relationship during all trials (r = 0.89 to 0.94).

4. Discussion

An important finding of this study was the achievement of the fastest run time during the most aggressive deception condition (Tri-Run$_{103\%}$), which was 14 seconds faster than Tri-Run$_{100\%}$ and 25 seconds faster than Tri-Run$_{97\%}$. Although these differences did not achieve statistical significance, magnitude-based inferences suggested that Tri-Run$_{103\%}$ performance was likely faster, and Tri-Run$_{97\%}$ likely slower, compared to other trials. Furthermore, both run and overall event ranking positions for the top 20 triathletes at the 2012 World Age-Group Sprint-Distance Championships were separated by an average of only 9 seconds [37]. It is therefore reasonable to suggest that the differences observed between each of the running conditions of the present study would be substantial enough to alter the outcome of non-elite, sprint-distance triathlon competition. Whilst this finding is consistent with previous deceptive [8] and non-deceptive [2,27] studies of initial pace manipulation, the present study is the first to highlight deceptive pace manipulation as a possible method to enhance performance during multi-disciplinary endurance events, such as triathlon. More importantly, these findings provide further evidence that expectations or beliefs play a key role in the brains regulation of exercise intensity so as to minimise the risk of harmful homeostatic disturbances. Indeed, it would appear that even during 'all-out' triathlon running, athletes maintain a substantial protective 'reserve' capacity which can be accessed by deception to improve performance.

Interestingly, our results appear to disagree with the suggestion that initially aggressive pacing strategies may be detrimental to triathlon running performance [22,23]. Since this concept is based on findings from Olympic-distance competition (1.5 km swim, 40 km bike, 10 km run), it may be that any benefit of an initially aggressive run pace is unique to the shorter sprint-distance triathlon format. Indeed, overcoming the time deficit associated with an initially conservative run strategy (i.e. up to 1.66 km) is thought to be more likely over 10 km compared to 5 km, due to the relatively greater distance remaining and relatively lower increases in speed required to do so [27]. That said, our findings indicate a non-significant trend for any 'lead' acquired during an aggressively paced run to increase over the final 1.66 km, rather than be diminished by more conservative strategies as the finish line draws closer (Fig. 1). It would therefore be of value for future studies to examine whether deceptive pace manipulation enhances performance during longer distance triathlon formats, whilst the selection and optimisation of pacing strategies during sprint-distance competition also warrants further investigation.

Despite being deceptively manipulated, imposed running speeds maintained a significant effect on metabolic and respiratory responses during the first 1.66 km of run performance, with greater physiological strain particularly evident for Tri-Run$_{103\%}$ compared to other trials (5.3 and 5.2% greater $\dot{V}O_2$; 8.8 and 3.1% greater $\dot{V}_E$; 21.9 and 6.8% greater [BLa^-], compared to Tri-Run$_{97\%}$ and Tri-Run$_{100\%}$, respectively). Furthermore, despite the negative effect of residual fatigue on the correlation between performance and physiological parameters during triathlon [38,39], physiological responses demonstrated the strongest associations with running speed over the course of each trial. It may therefore appear that, when regulating pace, the sensitivity of the brain to changes in physiological afferent signals supersedes an athlete's expectations or intentions regarding performance. As such, respiratory and metabolic disturbances have been proposed as key factor in the selection and maintenance of optimum pace during triathlon running [20], particularly when following the imposition of initially aggressive pacing strategies [2]. However, our findings suggest that physiological disturbances may only be indirectly related to, rather than a direct cause of, self-selected exercise intensity. Indeed, all triathletes successfully maintained the speed imposed during the first 1.66 km of each triathlon run (i.e. they did not succumb to preliminary fatigue or task failure), before consciously deciding whether to change their pace by actively pressing the treadmill controls. We therefore consider it unlikely that participants were simply 'slaves' to the physiological disturbances associated with faster running speeds. Instead, the observed changes in running speed appear to be reflective of the centrally located forecasting process proposed by Tucker [3], which calculates whether levels of physiological strain can be safely maintained for the remainder of an event and adjusts exercise intensity accordingly. This is supported by the achievement of an 'end-spurt' in the final 400 m of each trial during the present study (Fig. 1), which is considered indicative of centrally-regulated pacing during triathlon running [2,40]. Indeed, this phenomenon illustrates that the conscious regulation of pace remains of greater importance than inhibitory afferent signals in the presence of deceptively manipulated feedback [41].

An alternate physiological explanation for faster performance during Tri-$Run_{103\%}$ may be that this initially aggressive pacing strategy accelerated $\dot{V}O_2$ kinetics, leading to a greater proportion of the energy requirement being supplied by oxidative processes and relative 'sparing' of anaerobic capacity during the first 1.66 km, compared to the more conservative starting strategies. Indeed, our findings of greater total oxygen consumption during the initial section of Tri-$Run_{103\%}$, together with no significant differences between conditions in end-exercise $\dot{V}O_2$ and [BLa^-], are in accordance with previous research of fast-start pacing strategies, albeit over a relatively shorter duration [42]. As such, initially aggressive pacing during the triathlon run may enhance performance via an increased oxidative contribution to energy expenditure which, in turn, extends the time before the finite anaerobic capacity is exhausted [42]. However, due to the limited periods and frequency of physiological measurement during the present study, further research is needed to elucidate the role of $\dot{V}O_2$ kinetics during aggressively paced endurance events, such as the triathlon.

Interestingly, there was no difference between running trials in the perceptual responses recorded for each 1.66 km section, whilst significant associations were evident between all perceptual measures and distance covered. Furthermore, physiological and perceptual measures appeared largely disassociated throughout all trials, consistent with previous non-deceptive research of triathlon running [20]. Thus, by manipulating performance expectations or beliefs, deceptively aggressive pacing interventions appear to improve performance by modifying athletes' perceptions of differing exercise intensities and levels of physiological strain. However, it is important to highlight that whilst any between-trial differences were not statistically significant, there was an apparent trend between perceptual responses and imposed running speeds during the first 1.66 km. Indeed, at 1.66 km the greatest levels of perceived muscular, thermal and respiratory strain, effort, and displeasure, were all demonstrated during Tri-Run$_{103\%}$, whereas the opposite was true during Tri-Run$_{97\%}$. It is possible that such a trend could be exacerbated over a longer distance (e.g. the 10 km run of Olympic-distance triathlon) and, in turn, have a greater impact on subsequent pacing. As such, it would be worthwhile for future studies to examine the effects of deceptive pace manipulation on perceptual responses and pace regulation during longer event formats than that of the present study (i.e. Olympic-distance triathlon, ultra-marathon). It is also noteworthy that once athletes were able to self-select running speed (i.e. 1.66 km onwards), values for perceptual responses appeared to converge before developing at a similar rate towards a common 'terminal' value (Fig. 3). Taken together, these findings suggest that whilst central processes of pace regulation appear to be somewhat reliant on task-specific performance expectations and beliefs, an athletes conscious intentions are secondary to the brains sensitivity to physiological and perceptual strain it considers as excessive in the context of the ‘protective threshold’ and distance remaining. As such, it would appear that the perceptual ‘template’ put forward by Tucker [3] is a relatively robust construct during self-paced performance. This is consistent with recent studies of cycling performance, which suggest the magnitude of deceptively aggressive pacing which can be sustained for long enough to benefit overall performance has relatively fine margins, which may be associated with established values of typical error and smallest worthwhile performance changes [7,8].

Lastly, it has been suggested that, compared to other perceptual responses, affect may be particularly important in the central regulation of pacing during endurance tasks, with more negative affect associated with reduced tolerance of physiological strain and poorer performance [17]. However, it would appear that the findings of the present study do not support this suggestion, with the most negative levels of affect apparent throughout the quicker, more aggressive, and thus more physiologically stressful, deception conditions (Figs. 2 and 3). Furthermore, we found affect to be just as weakly related to physiological responses as other perceptual measures. That said, a number of findings from the present study corroborate with those of Renfree et al. [17] whereby more aggressive pacing strategies, and greater levels of metabolic strain, are associated with superior endurance performance. Performance enhancement by deception may therefore result from an altered association within the brain between affect and physiological strain, leading to a greater willingness to persevere with workloads that would otherwise be considered unsustainable. It is also possible that triathletes associate negative affect with more successful performance, embracing the ability or willingness to withstand ‘suffering’ as an essential part of the sport [43]. This certainly warrants further study in relation to differing triathlon distances and ability levels, whilst future studies may also examine the possibility of discipline or sport-specific relationships between affect and performance to gain a better understanding of potential performance-enhancing interventions [17].

5. Conclusions

Extending the findings of previous research [7,8,10-13], this novel study demonstrates the potential for deceptive pacing interventions to elicit practically meaningful changes in multi-disciplinary endurance performance. Despite previous suggestions to the contrary [22,23], a deceptively aggressive initial pace appears to produce a better overall run performance during sprint-distance triathlon, compared to more conservative starting strategies. Whilst this suggests that existing expectations and beliefs can strongly influence pace regulation, and may allow an individual to access a previously untapped physiological ‘reserve’, it is apparent that any conscious intentions are secondary to the brains sensitivity to potentially harmful levels of physiological and perceptual strain. As such, future studies may examine the impact of negative effect on performance optimisation and pacing in longer formats of triathlon, and also across a wider range of sports. Future pacing research should also consider moving away from abstract explanatory constructs such as the performance ‘template’, or ‘central governor’, and instead strive to examine specific brain regions and pathways which are responsible for the regulation of pacing, both in deceptive and non-deceptive contexts.

Conflicts of interest

The authors have no conflicts of interest to declare.

Acknowledgments

The authors would like to thank Veronica Vleck for her valuable input, Flo Ashdown, Daisy Bruce, Tom Collins, Nicole Graur, Jodie Levick, Tom Nicholson, Amy Page, Lewis Stukins and Ryan Willows for their support during field triathlon data collection, and Simon George for his excellent technical support.

References

[1] Foster C, Koning JJ, Hettinga F, et al. Effect of competitive distance on energy distribution during simulated competition. Int J Sports Med 2003;25:198-204.

[2] Hausswirth C, Le Meur Y, Bieuzen F, et al. Pacing strategy during the initial phase of the run in triathlon: Influence on overall performance. Eur J Appl Physiol 2010;108:1115-23. doi:10.1007/s00421-009-1322-0.

[3] Tucker R. The anticipatory regulation of performance: The physiological basis for pacing strategies and the development of a perception-based model for exercise performance. Br J Sports Med 2009;43:392-400. doi:10.1136/bjsm.2008.050799.

[4] de Koning JJ, Foster C, Bakkum A, et al. Regulation of pacing strategy during athletic competition. PloS One 2011;6:e15863. doi:10.1371/journal.pone.0015863.

[5] Gibson ASC, Lambert EV, Rauch LHG, et al. The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. Sports Med 2006;36:705-722.

[6] Mauger AR, Jones AM, Williams CA. The effect of non-contingent and accurate performance feedback on pacing and time trial performance in 4-km track cycling. Br J Sports Med 201;45:225-9. doi:10.1136/bjsm.2009.062844.

[7] Micklewright D, Papadopoulou E, Swart J, et al. Previous experience influences pacing during 20 km time trial cycling. Br J Sports Med 2010;44:952-960. doi:10.1136/bjsm.2009.057315.

[8] Stone MR, Thomas K, Wilkinson M, et al. Effects of deception on exercise performance: implications for determinants of fatigue in humans. Med Sci Sports Exerc 2012;44:534-41. doi:10.1249/MSS.0b013e318232cf77.

[9] Swart J, Lamberts RP, Lambert MI, et al. Exercising with reserve: exercise regulation by perceived exertion in relation to duration of exercise and knowledge of endpoint. Br J Sports Med 2009;43:775-81. doi:101136/bjsm2008056036.

[10] Beedie CJ, Lane AM, Wilson MG. A possible role for emotion and emotion regulation in physiological responses to false performance feedback in 10 mile laboratory cycling. Appl Psychophysiol Biofeedback 2012;37:269-77. doi:10.1007/s10484-012-9200-7.

[11] Faulkner J, Arnold T, Eston R. Effect of accurate and inaccurate distance feedback on performance markers and pacing strategies during running. Scand J Med Sci Sports 2011;21:e176-83. doi:10.1111/j.1600-0838.2010.01233.x.

[12] Thomas G, Renfree A. The effect of secret clock manipulation on 10 km cycle time trial performance. Int J Arts Sci 2010;3:193-202.

[13] Wilson MG, Lane AM, Beedie CJ, et al. Influence of accurate and inaccurate 'split-time' feedback upon 10-mile time trial cycling performance. Eur J Appl Physiol 2012;112:231-6. doi:10.1007/s00421-011-1977-1.

[14] Eichner ER. Placebos for athletes: do they exist? If not, do they work anyway? Curr Sports Med Rep 2013;12:134-135. doi:10.1249/JSR.0b013e3182935fcd.

[15] Bentley DJ, Cox GR, Green D, et al. Maximising performance in triathlon: Applied physiological and nutritional aspects of elite and non-elite competitions. J Sci Med Sport 2008;11:407-16.

[16] Hettinga FJ, De Koning JJ, Broersen FT, et al. Pacing strategy and the occurrence of fatigue in 4000-m cycling time trials. Med Sci Sports Exerc 2006;38:1484-91.

[17] Renfree A, West J, Corbett M, et al. Complex interplay between determinants of pacing and performance during 20 km cycle time trials. Int J Sports Physiol Perform 2012;7:121-9.

[18] Hampson DB, Gibson ASC, Lambert MI, et al. Deception and perceived exertion during high-intensity running bouts. Percept Mot Skills 2004;98:1027-38.

[19] Jameson C, Ring C. Contributions of local and central sensations to the perception of exertion during cycling: effects of work rate and cadence. J Sports Sci 2000;18:291-8.

[20] Taylor D, Smith MF. Scalar-linear increases in perceived exertion are dissociated from residual physiological responses during sprint-distance triathlon. Physiol Behav 2013;118: 178-84. doi:10.1016/j.physbeh.2013.05.031.

[21] Bentley DJ, Vleck VE. Pacing strategy and performance in elite world cup triathlon: a preliminary study. Med Sci Sports Exerc 2004;36:S122.

[22] Le Meur Y, Bernard T, Dorel S, et al. Relationships between triathlon performance and pacing strategy during the run in an international competition. Int J Sports Physiol Perform 2011;6:183-94.

[23] Vleck VE, Bentley DJ, Millet GP, et al. Pacing during an elite Olympic-distance triathlon: comparison between male and female competitors. J Sci Med Sport 2008;11:424-32.

[24] Sultana F, Abbiss CR, Louis J, et al. Age-related changes in cardio-respiratory responses and muscular performance following an Olympic triathlon in well-trained triathletes. Eur J Appl Physiol 2012;112:1549-56. doi:10.1007/s00421-011-2115-9.

[25] Taylor D, Smith MF, Vleck VE. Reliability of performance and associated physiological responses during simulated sprint-distance triathlon. J Sci Cycling 2012;1:21-9.

[26] McGawley K, Shannon O, Betts J. Ingesting a high-dose carbohydrate solution during the cycle section of a simulated Olympic-distance triathlon improves subsequent run performance. Appl Physiol Nutr Metab 2012, 37(4), 664-671.

[27] Gosztyla AE, Edwards DG, Quinn TJ, et al. The impact of different pacing strategies on five-kilometer running time trial performance. J Strength Cond Res 2006;20:882-6.

[28] Hue O, Le Gallais D, Prefaut C. Specific pulmonary responses during the cycle-run succession in triathletes. Scand J Med Sci Sports 2001;11:355-61.

[29] Borg G. Borg's perceived exertion and pain scales. Champaign (IL): Human Kinetics; 1998.

[30] Astorino TA, Cottrell T, Talhami Lozano A, et al. Effect of caffeine on RPE and perceptions of pain, arousal, and pleasure/displeasure during a cycling time trial in endurance trained and active men. Physiol Behav 2012;106:211-7. doi:10.1016/j.physbeh.2012.02.006.

[31] Hardy CJ, Rejeski WJ. Not what, but how one feels: The measurement of affect during exercise. J Sport Exerc Psychol 1989;11:304–17.

[32] Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14:377–81.

[33] Swart J, Lindsay TR, Lambert MI, et al. Perceptual cues in the regulation of exercise performance–physical sensations of exercise and awareness of effort interact as separate cues. Br J Sports Med 2012;46:42-8. doi: 10.1136/bjsports-2011-090337.

[34] Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform 2006;1:50-7.

[35] Hopkins WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p-value. Sportscience. 2007;11:16-20.

[36] Vescovi JD, Mcguigan MR. Relationships between sprinting, agility, and jump ability in female athletes. J Sports Sci 2008;26:97-107.

[37] International Triathlon Union. World Triathlon Grand Final Auckland. Accessed 01 June:http://www.multisportaustralia.com.au/RaceTecResults/Results.aspx?CId=1&RId=751&EId=1:2013.

[38] Laursen PB, Rhodes EC. Factors affecting performance in an ultraendurance triathlon. Sports Med 2001;31:195-209.

[39] Millet GP, Vleck VE. Physiological and biomechanical adaptations to the cycle to run transition in Olympic triathlon: review and practical recommendations for training. Br J Sports Med 2000;34:384-90.

[40] Le Meur Y, Thierry B, Rabita G, et al. Spring-Mass Behaviour during the Run of an International Triathlon Competition. Int J Sports Med 2013;34:1-8. doi:10.1055/s-0032-1331205.

[41] Marcora S. Counterpoint: Afferent feedback from fatigued locomotor muscles is not an important determinant of endurance exercise performance. J Appl Physiol 2010;108:454-6. doi:10.1152/japplphysiol.00976.2009a.

[42] Jones AM, Wilkerson DP, Vanhatalo A, et al. Influence of pacing strategy on O_2 uptake and exercise tolerance Scand J Med Sci Sports 2008; 18:615-26.

[43] Atkinson M. Triathlon, suffering and exciting significance. Leisure studies 2008;27:165-80.

Figure legends

Figure 1 Cumulative times for each 1.66 km section completed in each running condition. Significantly different from Tri-Run$_{97\%}$ value, ^{a} P<0.05, ^{aa} P<0.01. Significantly different from Tri-Run$_{100\%}$ value, ^{b} P<0.05, ^{bb} P<0.01. Significantly different from Tri-Run$_{103\%}$ value, ^{c} P<0.05, ^{cc} P<0.01.

Figure 2 Mean running speed for each 1.66 km (solid lines) and 200 m (dashed lines) completed in each running condition (error bars removed for clarity).

Figure 3 Mean blood lactate concentration ([BLa$^-$]), heart rate, oxygen uptake ($\dot{V}O_2$), ventilation ($\dot{V}_E$) and respiratory exchange ratio (RER) for each 1.66 km section of all running trials (error bars removed for clarity). Significantly different from initial Tri-Run$_{100\%}$ value, ^{b} P<0.05. Significantly different from initial Tri-Run$_{103\%}$ value, ^{c} P<0.05, ^{cc} P<0.01. Significantly different from initial Tri-Run$_{100\%}$ value, ^{BB} P<0.01.

Figure 4 Mean ratings of perceived muscular pain, effort, breathlessness, affect and thermal discomfort for each 1.66 km section of all running trials (error bars removed for clarity). Significantly different from initial Tri-Run$_{97\%}$ value, ^{a} P<0.05, ^{aa} P<0.01. Significantly different from initial Tri-Run$_{100\%}$ value, ^{b} P<0.05, ^{bb} P<0.01. Significantly different from initial Tri-Run$_{103\%}$ value, ^{c} P<0.05. Significantly different from previous Tri-Run$_{97\%}$ value, ^{A} P<0.05. Significantly different from initial Tri-Run$_{100\%}$ value, ^{B} P<0.05.

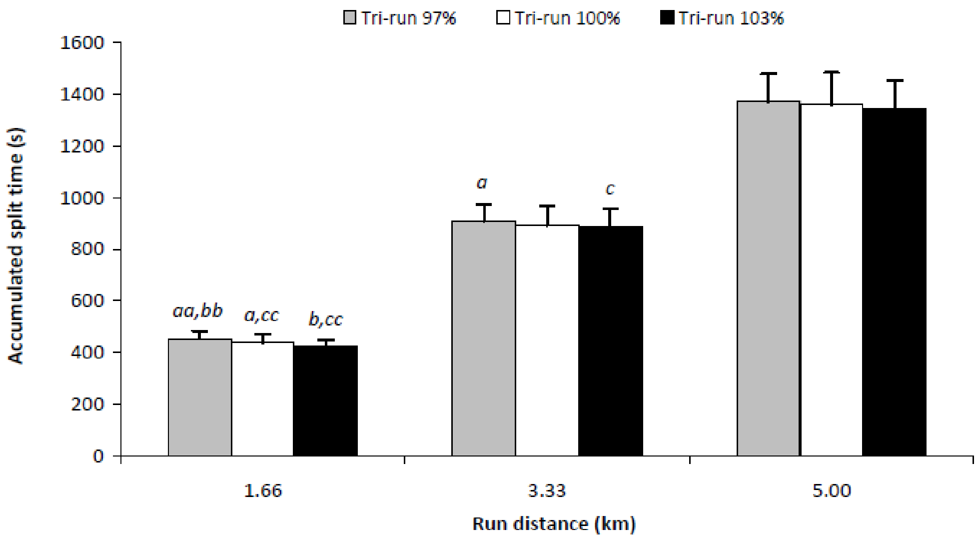
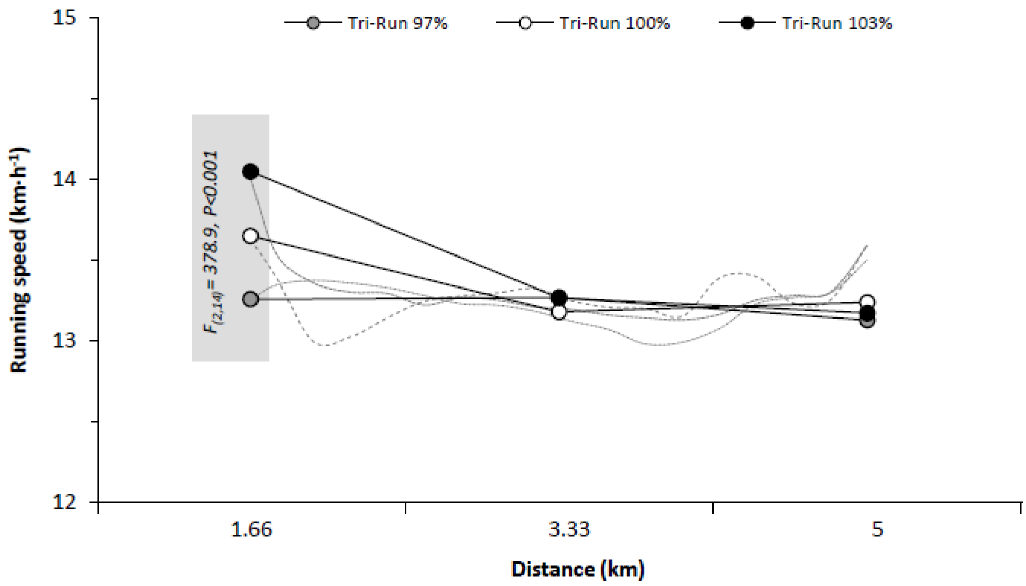
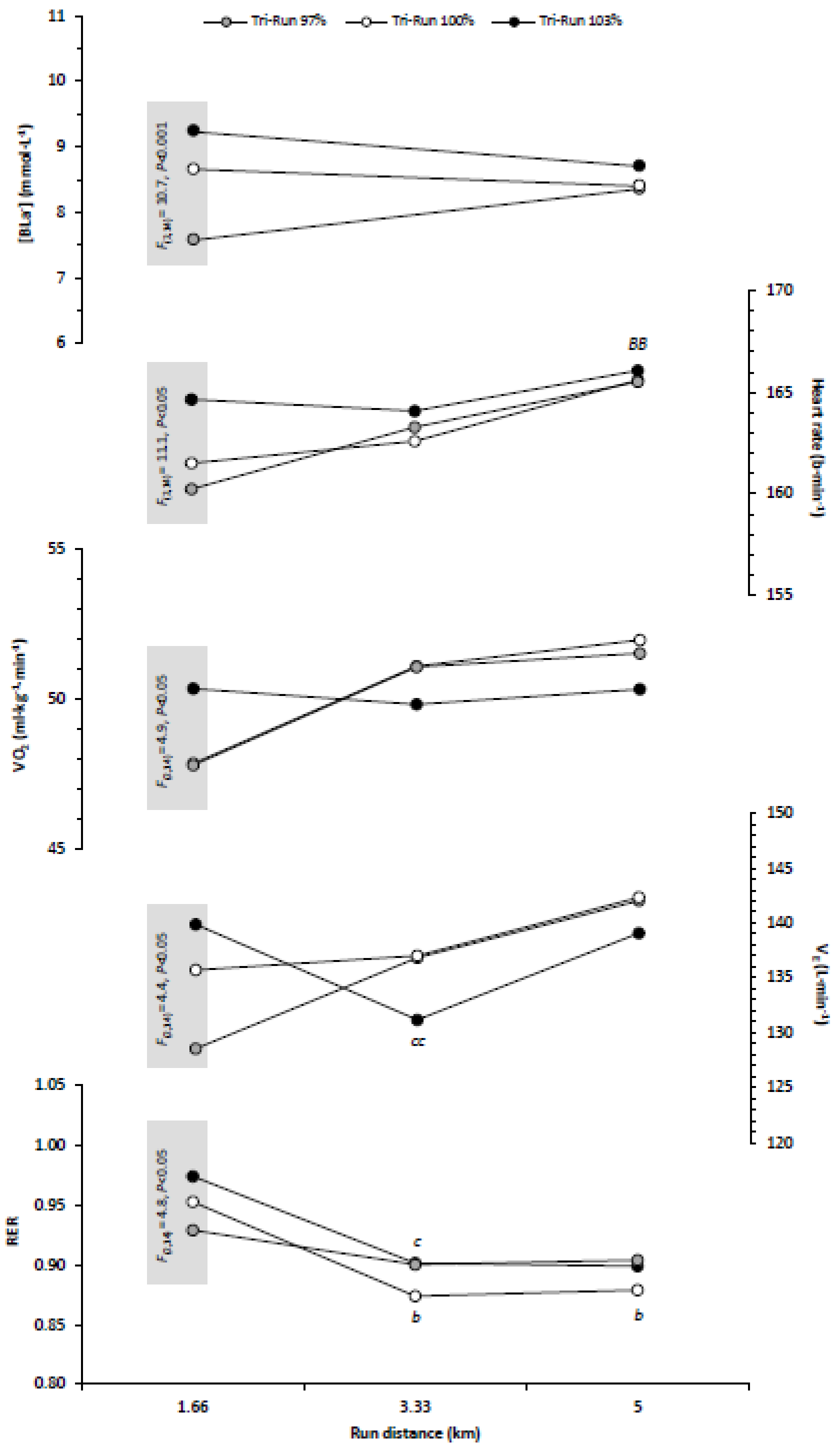

Tri-run 97%
Tri-run 100%
Tri-run 103%
Accumulated split time (s)
1600
1400
1200
1000
800
600
400
200
0
aa,bb
a,cc
b,cc
a
c
1.66
3.33
5.00
Run distance (km)

Figure 1



Tri-Run 97%
Tri-Run 100%
Tri-Run 103%
15
14
13
12
Running speed (km·h⁻¹)
$F_{(2,14)}$ = 378.9, P<0.001
1.66
3.33
5
Distance (km)

Figure 2



Tri-Run 97%
Tri-Run 100%
Tri-Run 103%
[BLa] (mmol·L-1)
Heart rate (b·min-1)
VO2 (ml·kg-1·min-1)
VE (l·min-1)
RER
BB
cc
c
b
b
1.66
3.33
5
Run distance (km)

Figure 3

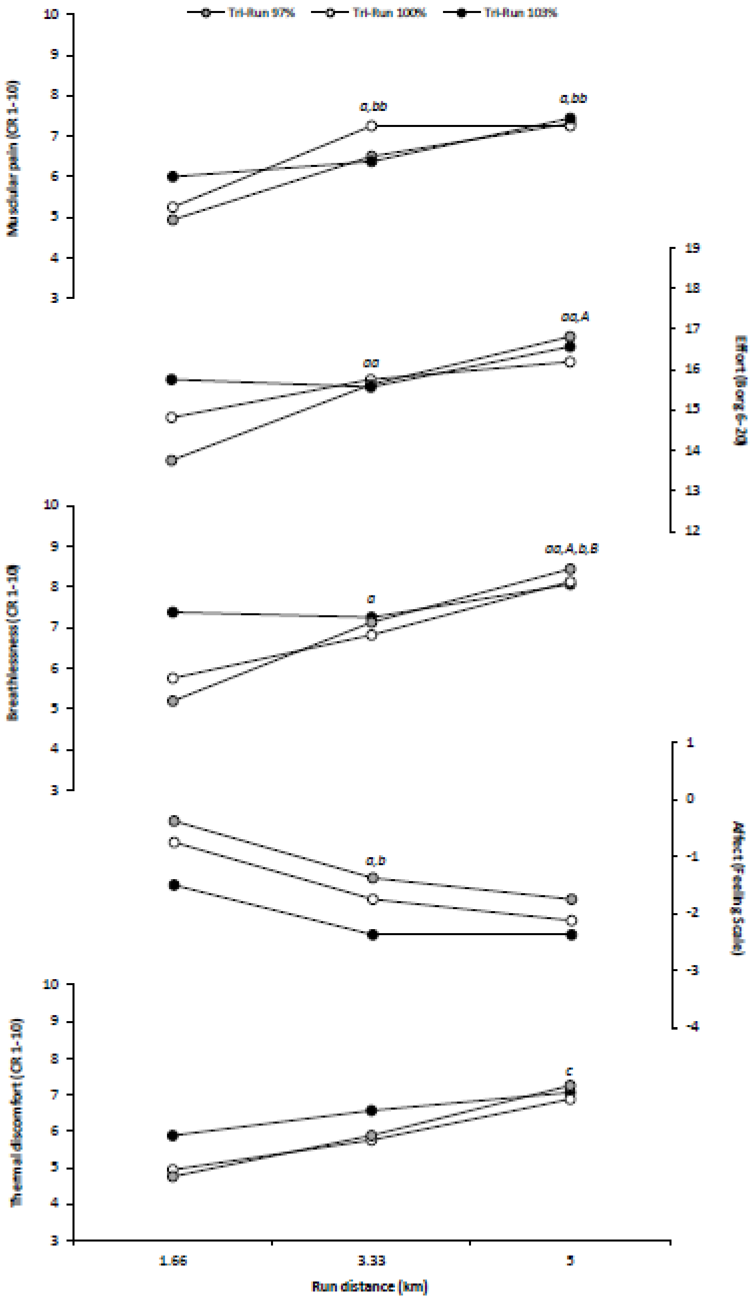

Tri-Run 97%
Tri-Run 100%
Tri-Run 103%
Muscular pain (CR 1-10)
Effort (Borg 6-20)
Breathlessness (CR 1-10)
Affect (Feeling Scale)
Thermal discomfort (CR 1-10)
Run distance (km)
1.66
3.33
5
a,bb
a,bb
aa
aa,A
a
aa,A,b,B
a,b
c

Figure 4

Highlights

- Deceptive pacing interventions elicit meaningful changes in triathlon performance.
- As such, running performance is enhanced by deceptively aggressive initial pacing.
- Greater negative affect is evident during quicker, more aggressive run performance.
- Deception encourages tolerance of workloads otherwise considered as unsustainable.
- However, conscious intent is secondary to critical levels of physiological strain.