Physiological and psychological effects of deception on pacing strategy and performance: A review

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Abstract

The aim of an optimal pacing strategy during exercise is to enhance performance whilst ensuring physiological limits are not surpassed, which has been shown to result in a metabolic reserve at the end of the exercise. There has been debate surrounding the theoretical models that have been proposed to explain how pace is regulated, with more recent research investigating a central control of exercise regulation. Deception has recently emerged as a common, practical approach to manipulate key variables during exercise. There are a number of ways in which deception interventions have been designed, each intending to gain particular insights into pacing behaviour and performance. Deception methodologies can be conceptualised according to a number of dimensions such as deception timing (prior to or during exercise); presentation frequency (blind, discontinuous or continuous); and type of deception (performance, biofeedback or environmental feedback). However research evidence on the effects of deception has been perplexing and the use of complex designs and varied methodologies makes it difficult to draw any definitive conclusions about how pacing strategy and performance are affected by deception. This review examines existing research in the area of deception and pacing strategies, and provides a critical appraisal of the different methodological approaches used to date. It is hoped that this critical analysis will inform the direction and methodology of future investigations in this area by addressing the mechanisms through which deception impacts upon performance and by elucidating the potential application of deception techniques in training and competitive settings.

1 Introduction

The Central Governor Model (CGM)[1–3] attributes changes in pace during exercise to a brain-derived regulatory strategy by a central governor in order to maintain an exercise reserve[4]. This is achieved through a continuous integration of afferent feedback from peripheral systems and feedforward signals, acting to protect the body from physiological failure[1]. Therefore the aim of an optimal pacing strategy during exercise is to enhance performance whilst ensuring physiological limits are not surpassed[5]. Pacing strategy is said to be influenced by feedback information from both internal and external cues[6]. Oxygen saturation, glycogen levels[7] and metabolic fuel reserves, for example, act not just as metabolic by-products, but as internal signallers[1]. On the other hand, environmental conditions such as gradient, terrain, weather, oxygen content of inspired air, knowledge of the event (for example distance or duration][8], previous experience[9,10] and competition[11,12] all equate to external cues[13–15].

Pacing strategy is proposed to be established pre-exercise, based upon experience-primed interpretation of these internal and external cues[10], resulting in the selection of work-rate or intensity by efferent neural commands sent from the central nervous system[1,3,15]. This subconscious, feedforward integration process has been termed "teleoanticipation"[16] and is a key element of the CGM[17]. Perception of effort, which is usually measured by a 10- or 16-point rating of perceived exertion (RPE) scale[18,19], represents an overall conscious awareness of the internal physiological state, sensations generated during physical activity and the known endpoint[5,20]. One proposition is that perceived exertion plays an anticipatory role in exercise regulation, as determined by changing patterns of physiological afferent feedback[21]. The model states that a 'template RPE' is set prior to the commencement of exercise based upon the expected exercise duration and the previous experience of similar bouts of exercise, which are two cues of teleoanticipation that are regarded as the most influential to the pacing strategy. Therefore, from the onset of exercise, the selected work-rate is said to be moderated so that a maximal RPE will occur at the endpoint of the exercise. Disparity between experienced RPE and template RPE provokes a pacing modification to restore an appropriate RPE trajectory, which coincides with the exercise end-point[22–25]. The RPE template has been shown to be set, not in accordance with the exercise intensity, but in relation to the exercise duration and to increase as a linear function of the percentage duration remaining[26,27] in such a way that the initial rate of increase can accurately predict the endpoint[28].

Further regulation of work-rate and the subsequent metabolic responses occurring throughout the exercise are continuously adjusted as feedback control mechanisms relay information from physiological peripheral systems, which are integrated in relation to external feedback[15,29]. This continuous adjustment of pacing strategy allows completion of the exercise without inducing catastrophic physiological failure. Throughout exercise, the integration of physiological afferent feedback and external performance feedback is compared to the template RPE and the remaining duration of the exercise at the current work-rate and a 'conscious RPE' is produced.

The resultant pacing strategy employed during exercise results in motor unit and metabolic reserves that are preserved in order to prevent this catastrophic physiological failure[12]. Therefore an athlete's absolute physiological capabilities are not reached and performance is thus not representative of a true maximal effort. The need for evidence to support the existence of this metabolic reserve at the completion of exercise consequently provides a rationale for the investigation into how this reserve can be accessed[4,30,31]. Obtaining an effort that is closer to maximal, by tapping into an athlete's true physiological capabilities, is of interest in order to help validate the model, improve performance and allow a more accurate comparability and consistency between competitive performances[32,33].

Deception has recently emerged as a common, practical approach to manipulate key variables during exercise. The manipulation of central psychological mechanisms, including the presence of a competitor[11,12] and hypnosis[34], as well as psychological skills training[35] have been reported to improve performance by accessing this reserve. Studies that have examined the placebo effect, using inert substances believed to be ergogenic, also report that false positive beliefs elicit performance improvements[36]. Altering perceptions of the exercise requires an element of deception in order to prevent the threat to internal validity from expectancy. However, whilst the manipulation of the provision of external feedback has been researched, evidence for the effects of the deception of this feedback on performance has been more equivocal. In the current body of literature, vast differences in methodology, including the variables manipulated, timing of the deception, training status of the participants, and the exercise modality, has created a field of research where conclusions are difficult to form and the underlying mechanisms cannot be established.

This review examines existing research in the area of deception and pacing strategies, and provides a critical appraisal of the different methodological approaches used to date. It is hoped that this critical analysis will inform the direction and methodology of future investigations in this area, by addressing the mechanisms through which deception impacts upon performance and by elucidating the potential application of deception techniques in training and competitive settings. Additional discussion of the ethical issues surrounding deception research are included, with recommendations made for future studies in the area.

A computer search in scientific databases (PubMed, Google Scholar and EBSCO) was made for English-language articles investigating deception in exercise for all time periods up to January 2013. Search terms included, but were not limited to, 'deception', 'manipulation', 'exercise', 'pacing', feedback', 'fatigue' and 'Central Governor Model'. The reference lists of all articles were also searched for additional relevant papers. All experimental investigations of treadmill and cycling exercise were reviewed and, whilst articles investigating deception in other exercise modes were noted[37–39], they were deemed beyond the scope of this review. Exclusion criteria were also extended to research into the effects of placebos[40,41] and pain manipulation[42,43] with delimitation to the deception of performance, physiological and psychological variable feedback.

2 Manipulation of Pre-exercise Expectations

A number of deception studies[44–48] (see Table 1) have manipulated the expectations of exercise prior to commencement, by providing false or no knowledge about the exercise endpoint. Theoretically, the deception of external feedback prior to exercise would cause physiological resources to be incorrectly allocated and create a discrepancy between the perceived and actual demands of the exercise. If the deception creates a situation where the duration of exercise is shorter than expected, then the participant will most likely not produce their best performance due to planning and executing a more conservative pacing strategy intended for a longer duration[21]. In contrast, if the participant is deceived such that the exercise duration is longer than expected, then premature fatigue, stopping, or significantly slowing down before the endpoint is the more likely outcome. This final point has been evidenced by Ansley et al.[8] who showed that cyclists expecting a 30-second Wingate test, but unknowingly performed a 36-second Wingate test, had a lower 30-36-second power output compared to the final six seconds of a correctly informed 30-second test. Such findings lend support for the notion of teleoanticipation in which knowledge of the endpoint, known as the 'anchor point', has a crucial role in the anticipatory setting of the pace[15]. Teleoanticipation has also been evidenced in multiple studies investigating the effect of unknown durations of exercise on performance[44–48]. These studies have investigated the importance of this prior knowledge of exercise duration and the empirical evidence of this theory during fixed-intensity treadmill exercise[44,46], fixed-intensity cycling exercise[44] and repeated cycling sprints[45].

2.1 Open-loop Exercise

Without prior knowledge of the distance of the exercise, the exercise is open-loop and this anchor point cannot be used to pre-set an optimal work-rate. In open-loop exercise, the role of previous experience is one of ensuring completion of the exercise rather than optimal performance. Rather than setting an end-point determined RPE trajectory, in open-loop exercise experience will be used to select a work-rate and associated performance template whereby RPE remains in a steady-state at a level the individual believes they can tolerate for protracted periods of time. Consequently, a lower work-rate and more conservative pace are expected during open-loop compared to equivalent duration closed-loop tasks. Crucially, this strategy improves the odds of completing the exercise of an unspecified duration, with participants attempting to complete the exercise more efficiently and conserve physiological resources by selecting a work-rate at a lower intensity and metabolic demand[13]. This is to ensure a sufficient reserve capacity is maintained in order to avoid premature fatigue and failure to complete the exercise in the anticipation of a longer duration[14].

During exercise of a fixed work-rate, pacing strategy cannot be altered via changes in work-rate, therefore in these situations, the effects of knowledge of duration on physiological and psychological responses are examined. Oxygen uptake, heart rate and other physiological variables may be measured to assess the efficiency of performance, and measures of RPE and affect reflect the cognitive sensations experienced. Baden et al.'s study[46] found that in a 20-minute treadmill exercise bout at a fixed intensity of 75% of peak speed, oxygen uptake was lower in the latter half of a trial in which the duration was unknown compared to a trial where the duration was known. Therefore a greater running economy and more efficient performance due to the uncertainty of the exercise provide support for Tucker's[21] model. However, the mechanisms by which efficiency was enhanced are currently unknown as no differences in RPE, heart rate or stride frequency were found between the unknown and known conditions. Contrasting results were found by Eston et al.[44] who replicated the study by Baden et al.[46] and also used a comparative cycling protocol. In both treadmill and cycling protocols, no differences in oxygen uptake between the unknown and known conditions were found, where treadmill speed and cycling power output were constant, indicating that economy was similar. However, whilst RPE was lower in the unknown condition in the treadmill protocol, supporting the central control of fixed work-rate exercise regulation via RPE, interestingly the same difference was not found in the cycling protocol. This finding was supported by Billaut et al.[45] who used a repeated sprint cycling protocol and also found no differences in RPE between trials where participants were not informed how many sprints they would be completing in comparison to an accurately informed trial. The finding of a lower accumulation of work over the ten, six second sprints in the unknown condition supports theory of self-paced exercise[21], where work-rate is expected to be set more conservatively. The inconsistency in the findings of RPE responses in open-loop exercise may be explained by differences in participant characteristics. As the endpoint is unknown, the RPE template will be set based on previous experience[21], which varied between these studies[44–46] as trained and untrained participants were used.

It should be also be noted that open-loop exercise, whether self-paced or of fixed intensity, is not something that most athletes will ever be required to perform either in training or competition. Open-loop exercise is usually used as an experimental model to investigate absolute limits of performance (often as time to exhaustion) or associated physiological and psychological responses, or as a comparator to understand the relevance of endpoint awareness on athletic behaviour. Consequently, this type of exercise may not be a suitable research design to adopt in future deception studies where the aim is to understand the regulation of athletic performance and the potential means of accessing a metabolic reserve to enhance this performance.

2.2 Unexpected Changes to the Exercise Endpoint

Studies by Baden et al.[46], Billaut et al.[45] and Eston et al.[44] have included trials where there was an unexpected increase in exercise duration. It has been proposed that performance will be negatively affected if the deception is consciously or subconsciously revealed or detected as the allocation of physiological resources will not have been set accurately; having been based on an incorrect expectation of the exercise duration prior to commencement[14]. Therefore, in studies where an unexpected change in duration is revealed during the exercise, theory predicts that performance will be worse than in a control condition and an adjustment to the performance template becomes necessary. In addition to the unknown and known duration trials in the previously discussed studies[44,46] where treadmill running is used, a third deceptive trial was completed where participants were informed they would be completing a 10-minute run but at 9-minutes they were asked to continue running for a further 10-minutes. In both studies, affect scores decreased and RPE increased when this deception was revealed. This indicates that there was a disruption in the feedback and feedforward mechanism and a mismatch was detected between the template and conscious RPE. The decline in affect scores and increase in RPE in Baden et al.'s[46] study was also linked to an increase in associative attentional focus. This suggests that the changes in RPE in the deception trials were due to psychological factors (i.e., affect and attentional focus) as no differences in physiological variables were reported in either study.

Similar to the unknown duration condition, contrasting results for RPE were also found in the trial where duration was unexpectedly increased during the cycling protocol[44]. Unlike in the treadmill protocols, RPE did not increase when the deception was revealed, which is contrary to the predictions of Tucker[21], and suggests that detectable adjustments in the performance template did not occur. Interestingly, however, affect decreased at the 10th minute, suggesting that this experience of pleasure/displeasure may be more sensitive than the gestalt measure of RPE. A further refute to Tucker's theory[14,21] is provided by the absence of an underperformance when the actual duration exceeded the expected duration, as power output and work accumulated were not statistically different to the control trial.

With a fixed work-rate at a fixed duration of exercise in these studies, the effects of knowledge of duration on pacing strategy could not be examined. In self-paced exercise, Billaut et al.[45] incorporated a deception trial by manipulating prior knowledge of the number of sprints to be completed. After completing an expected five sprints in the deception trial, participants were instructed to complete an additional five sprints. Power output, work and sum of integrated electromyography (iEMG) in the initial sprint, and work and sum-iEMG accumulated in the first five sprints, were higher in the deception trial than both unknown and control trials, where ten sprints were knowingly completed. This may be indicative of changes in central motor unit control strategies and supports the notion that pacing strategy was set prior to exercise based upon the anticipation of a lower number of sprints. However, in contrast to the findings of recent treadmill investigations[44,46] and Tucker's[21] theory, no change in RPE (which was measured after each sprint) was found in the deception condition when the unexpected increase in number of sprints was revealed. Unfortunately, however, affect was not measured which, based on Eston et al.'s findings[44], could have provided an explanation as to the role of the psychological mechanisms underpinning exercise regulation. Future research investigating the effects of the manipulation of pre-exercise expectations should consider the need for more experiential measures, namely psychological constructs such as affect and attentional focus, to further inform understanding of what mechanisms may be responsible for changes in exercise regulation and performance.

2.3 False Expectations of the Exercise Endpoint

Another form of deception employed prior to exercise to alter the expectation of the endpoint is the provision of incorrect knowledge of the exercise duration, or distance to be completed. As discussed, theory states that incorrect knowledge of the exercise duration will result in an impairment in performance due to an incorrect allocation of physiological resources[14]. Ansley et al.[8] provided support for the role of conscious control even in maximal, all-out exercise. In comparison to correctly informed trials, as previously described, power output was only lower during the final six seconds of the 36-second deception trial when the discrepancy between expected and actual duration was most significant. It was concluded that the mismatch was only detected in these final six seconds and with an incorrect allocation of physiological resources, performance was impaired[14].

Nikolopolous et al.[33] replicated a study by Palmer et al.[49] and supported results that deception of the distance of self-paced cycling time-trials (TT) did not affect performance with well-trained cyclists. Participants were informed that all trials would be 40 km but a 15% deception meant 34 km and 46 km TT's were also completed and were subsequently compared to accurately informed trials of these distances. These results also support Ansley et al.[8] in that pacing strategy was based on the perceived distance and not the actual distance and, due to a smaller percentage discrepancy between the false and accurate distances, similar pacing strategies and performance times were found between the deception and control trials. However participants had external feedback of the percentage of the remaining distance which would progressively reduce the discrepancy between perceived and actual distance allowing them to continuously adjust their pacing strategy throughout exercise.

Critiquing the provision of distance and physiological feedback in the Nikolopolous et al.[33] study, Paterson and Marino[9] aimed to evaluate the effect of the deception of the endpoint when this continuous external feedback was not given in successive cycling TT's. Although limited participant numbers could explain why Nikolopolous et al.[33] found no statistical differences between trials, Paterson and Marino[9] believed that the effects of deception on pacing strategy would only be manifest in an additional subsequent trial, identical to an accurate initial trial. Therefore the experimental group in their study performed three trials: TT1, consisting of a known 30 km distance; TT2, where participants were deceived to complete a longer (36 km) or shorter distance (24 km) than an expected 30 km; and TT3, consisting of a final time-trial of a known 30 km distance. The control group completed three 30 km TT's of known distance. No differences in completion time or power output were found between TT1 and TT2 in any condition which is comparable to the results found by Nikolopolous et al.[33]. However, when the subsequent TT was completed, a greater power output and faster completion time in the longer distance group were found in comparison to both other conditions and to the group's initial TT. These results suggest that an effort template[21] and pacing schema produced from the initial trial, was altered following the deception in TT2, but this adjustment was only manifest in TT3. This evidence proposes that the role of previous experience (e.g., schemas stored in long-term memory, developed through previous stimulus exposure) on pacing strategy is more influential than knowledge of the endpoint (e.g., situational knowledge stored in short-term memory) and supports the anticipatory RPE model[21]. This has also been evidenced in a study by Mauger et al.[47], discussed further in a subsequent section of this review, where previous experience of exercise of an unknown duration and without feedback was attributed to the improvements in performance over repeated trials.

2.4 False Expectations of the Exercise Intensity

Two studies[50,51] have investigated the effects of pre-exercise deception of exercise intensity on performance and found no differences in any variables measured. In one study of closed-loop treadmill exercise, Hampson et al.[51]

found that RPE and heart rate responses were similar between a trial in which participants were deceived of the intensity (set as a percentage of their peak speed) and incorrectly informed of the true percentage prior to the exercise, and a trial where they were correctly informed of the intensity. Similarly, Pires and Hammond[50] found no differences in time to exhaustion or heart rate in open-loop cycling trials continued to volitional exhaustion where deception of the intensity was implemented using Borg's[18] RPE scale. In the deception trial, participants were informed they would be cycling at a fixed power output that corresponded to an RPE score two units lower than the true RPE score. This was compared to a trial where the power output and RPE value were correctly communicated. The results from these studies suggest that deception of the exercise intensity does not affect the regulation or RPE template of fixed power output exercise and suggests that the role of knowledge of the endpoint and previous experience in exercise regulation may be more influential. However, few studies[50,51] have investigated the deception of intensity and these studies have differed markedly in the methodology employed, such as variation in how the deception was employed, closed versus open-loop protocols, and differences in the training status of participants. Future research may endeavour to investigate whether pre-exercise expectations of the exercise intensity are as influential to the anticipatory setting of pacing strategy as previous experience and knowledge of the endpoint.

3 Manipulation of External Feedback during Exercise

The previously discussed studies all used deception to manipulate expectations prior to exercise commencement, investigating the anticipatory element of pacing strategy. Other studies in this area (see Table 1) have investigated the role of congruent external feedback, which is provided during the exercise bout. With correct knowledge of the duration and previous experience of the exercise, an anticipatory setting of initial work-rate and template RPE can be made. Afferent physiological feedback and external performance feedback are interpreted to produce a conscious RPE. In exercise where the endpoint is known, but inaccurate performance feedback is provided, a conflict is provoked between experienced and expected RPE. Tucker's[21] model predicts that with correct prior knowledge of the exercise duration, the provision of incorrect time or distance feedback should not result in a change in performance in comparison to control conditions if the deception is sufficiently small to not be consciously detected.

3.1 Discontinuous Verbal Feedback

External feedback has been manipulated by the provision of inaccurate verbal feedback given at intervals throughout the exercise, namely splits every kilometre or mile[13,29,52,53]. The duration of the exercise is known but participants are deceived that they are closer to, or further away from, the endpoint of the exercise via the manipulation of feedback regarding the distance covered, or the time elapsed.

No differences in completion time, pacing strategy, or RPE were found in Albertus et al.'s study[29] of 20 km TT's when well-trained cyclists received accurate, delayed, premature and randomly-timed distance feedback[29]. This suggests that the initial anticipatory work-rate, based on the expected duration and previous experience, was more critical to the regulation of pace than the external distance feedback provided throughout exercise. Similarly, another study[13] found that completion time and pacing strategy did not differ between accurate and inaccurate feedback conditions. Using a similar protocol to Albertus et al.[29], accurate, premature and delayed distance feedback were provided to untrained participants during 6 km treadmill TT's. In the delayed feedback trial, participants maintained a faster running velocity for longer, which enabled a 5% faster completion time, which although not statistically significant, is double the 2.5% difference deemed to be represent a meaningful change in TT performance[54]. However, this difference was in comparison to a blind feedback condition and not the accurate feedback condition, thereby supporting Albertus et al.'s[29] results and the perhaps more significant role of correct duration knowledge.

Two further studies examined the effects of false positive and false negative time feedback on 10-mile cycling TT performance with well-trained cyclists[52,53]. Time elapsed feedback was given verbally to participants at 1-mile markers 5% ahead of true values in false positive conditions and 5% behind in false negative conditions, with no differences in completion time and power output between conditions[52]. Wilson et al.[53] also reported additional data from accurate and blind feedback trials, finding no differences between the four feedback conditions. The results from these feedback studies suggest that TT completion time does not differ between false and accurate trials where discontinuous verbal feedback is provided throughout exercise.

Whilst these feedback conditions elicited similar TT performances, there were marked differences in the physiological responses to the bouts. Beedie et al.[52] was also the only feedback study that measured emotions to identify possible underlying psychological mechanisms that could explain how belief effects, manipulated via deception, could affect performance. In addition to lower oxygen uptake and higher blood glucose, more 'positive' emotions and less effort needed to regulate emotions were reported in the false positive feedback conditions compared to the negative feedback condition. Greater energy cost has been associated with the regulation of emotions[55,56] and therefore suggests that emotions could have a mediating role between belief effects and performance, and suggests that the positive feedback in this study may have lowered the metabolic cost of movement. Mauger et al.[57] also speculated that the higher proportion of positive feedback responses, given in a trial where correct split time feedback was provided in comparison to a false feedback trial, elicited motivational benefits which allowed a faster time to completion. Future studies on deception that measure psychological variables, such as emotions and motivation, are warranted to further explore these possible mechanisms.

3.2 Blind Interventions Where No Feedback is Given

Studies blinding participants to any external feedback have provided inconsistent results[10,13,47,48,53]. Theory[21] states that with knowledge of the endpoint but no external feedback such as speed, time elapsed, or distance covered provided during the exercise, these cues cannot be used to regulate pace in accordance to the endpoint. This creates an element of uncertainty and an incorrect calculation of conscious RPE, resulting in an underperformance. Put simply, blinded participants are deprived of the information they need to make the on-going pacing adjustments necessary to maintain the appropriate RPE trajectory. In support of this, Faulkner et al.[13] found that pacing strategy and completion time were significantly slower, with corresponding lower heart rate and oxygen uptake, in a blind feedback condition than accurate feedback and delayed feedback conditions. This underperformance, and the similar RPE scores between trials, is comparable to a previously discussed study[45] of open-loop exercise suggesting that blind feedback may have similar effects on performance as blind duration. However, Wilson et al.[53] contrastingly reported that, whilst no differences were found in completion times, power output or heart rate, oxygen uptake and ventilation were higher in the false negative and blind feedback conditions than in false positive and accurate feedback conditions. Once more, the mechanisms are unknown but emotion regulation or motivation may have played a role in this increase in metabolic strain when false negative or no feedback was provided[52,57].

Two studies[47,48] have assessed the effect of exercising without knowledge of duration in self-paced exercise where participants also had no previous experience of the exercise and received no external feedback. Mauger et al.[47] found that over four successive 4 km cycling TT’s, TT1 was significantly slower in the blind condition compared to TT1 of the control condition where the duration was known and feedback was provided throughout. This finding supports existing theoretical constructs and previous studies stating that an underperformance occurs in exercise of an unknown duration[21,45]. In the experimental condition, participants were informed that each TT would be of equal distance but no distance knowledge or feedback was given. As the difference in completion time was reduced over successive TT’s, it was concluded that previous experience was more influential to developing a pacing strategy than external feedback, which complements previous findings[9,10]. These findings were not, however, replicated in a similar study using untrained participants[48]. Trained athletes may be better able to form pacing schemas based on their training experience compared to novices, which may explain the discrepancy between these two studies and suggest that the role of previous experience and distance feedback differs between trained and untrained participants.

In situations where participants have been blinded to performance feedback, inconsistent results have been reported. The effective interpretation of the findings is confounded by variations in the exercise protocols, level of previous experience and participants' training status. The mechanisms that can explain these differences are uncertain, particularly in self-paced performance trials. Very little is also known about the psychological strategies blinded participants adopt to estimate their progression.

3.3 Continuous Visual Feedback

External feedback displayed continuously throughout exercise via a running clock, physiological performance variables, or profile of a comparable performance projected on-screen has been manipulated to create a discrepancy between perceived and actual performance. Micklewright et al.[10] investigated the effect of previous experience and performance feedback on successive 20 km cycling TT's. Three groups (blind, accurate and false feedback) completed three trials in which all groups received accurate feedback in the third TT. In trials one and two in the false feedback group, participants' perceived performance was 5% better than actual performance via the manipulation of speed and distance covered feedback. The blind feedback group showed improvements in performance from TT2 to TT3 but no differences in completion time or average speed were found in the accurate or false feedback groups. An alteration of pacing strategy in the false feedback group was shown with a reduced cadence and greater power output in the first 5 km of TT3 compared to TT2. With the perception that their performance was greater than what it actually was in the deception trials, participants were able to use previous experience to enhance their belief effects. This is predicted to influence perceived exertion and pacing strategy, consequently improving performance in successive trials and thus supporting results found by Paterson and Marino[9]. However, unlike in this previous study[9], an initial trial with accurate feedback was not completed so it is unknown whether the greater power output seen in TT3 was also evident in comparison to a previous baseline performance. It is also uncertain how proposed belief effects act as a mechanism as no psychological measurements, such as self-efficacy, were taken.

An initial improvement in pace was reported in TT3 when compared to TT2 in the false feedback group. However, this elevated power output could not be sustained and power and speed fell after 13 km[10]. A 5% deception therefore may have been too large and conscious or subconscious control may have governed a reduction in work-rate to prevent excessive discomfort or homeostatic failure, consequently negatively affecting performance. This also lends support to the expected consequence of an incorrect comparison between the anticipatory RPE template and conscious RPE of premature fatigue[21]. However, RPE was not measured in TT1 or TT2 and statistical differences between RPE in TT3 between feedback conditions were not reported.

Stone et al.[12] recognised that, in relation to Tucker's[21] theory, the 5% deception used in Micklewright et al.'s[10] study was likely too large a discrepancy and was subconsciously detected. Therefore a 2% deception was employed based upon typical error values and smallest worthwhile change in 4 km cycling TT's[58]. Participants performed a baseline trial that was projected onto a screen as an avatar in a subsequent deception trial. Participants believed the visual performance profile of the avatar represented their baseline performance; however it was manipulated to display a profile of 102% of the baseline. Results showed that deception trials were significantly faster and had a higher mean power output than both an accurate feedback condition and the baseline performance, suggesting that the deception of intensity based on a previous trial was beneficial to TT performance. Corbett et al.[11] also used the presence of a simulated competitor, deceiving participants that it was an athlete of similar ability when it was in fact their own baseline performance, and further supported Stone et al.'s[12] findings. A faster time to completion and alteration in pacing strategy in a 2 km cycling TT were reported in the trial with head-to-head competition, in comparison to familiarisation and ride-alone trials. Other improvements in performance have been evidenced in studies that have used deception of external feedback to create a perception of performance that is worse than actual performance. Morton[32] used open-loop, cycling trials to exhaustion at a fixed power output showing results that a 10% slower running clock elicited longer times to exhaustion in males than a correctly calibrated-clock trial. However, as no other physiological or psychological variables alongside time to exhaustion were measured and no typical error reported, the possible mechanisms as to why significant differences were found, if they did indeed lie outside the typical error of measurement, are speculative. In a more recent study[59], 10 km cycling TT performances were reportedly unchanged by 10% clock manipulations, but the magnitude of the end spurt was greater in a slow clock condition than a fast clock condition in a 10 km cycling TT. A study by Parry et al.[6] employed a visual manipulation of optic flow in 20 km cycling TT's via projected video footage of a road being travelled along. Participants were instructed to match the power output profile and cadence to the average values of a baseline trial however the speed of the video footage was manipulated so it was 15% faster or slower than the actual speed at which they were performing. When speed was shown to be 15% slower than actual speed, and therefore the perception of performance was lower than the actual performance, power output was greater whilst RPE was lower.

Different mechanisms were proposed in each of these studies to explain why performance improved. Stone et al.[12] and Corbett et al.[11] both showed that in the final 10% and 50% of the deception trials, respectively, there was a greater contribution from anaerobic energy sources that resulted in the increases in power output and faster completion time. Alternatively, Parry et al.[6] stated that a shallower rate of RPE increase, and an increase in work-rate to complete the exercise sooner, resulted in an increase in power output. Morton[32] and Faulkner et al.[13] both suggested that effort is increased to rectify a poorer performance, suggesting that motivation is a contributing factor. However, the latter conclusion was made in relation to 'competitive' individuals despite neither study using well-trained athletes, or providing supporting evidence of changes in RPE[13,32]. With differences in the nature of the feedback deception and exercise protocols between these studies, it may not be realistic to expect that a single, common mechanism is responsible for changes in performance and it is more likely that, rather than acting mutually exclusive, these proposed physiological and psychological mechanisms occur in a mediating and causal manner. However, with an overall lack of supporting evidence, for example none of the aforementioned studies measured any psychological variables other than RPE, the purported mechanisms require further investigation. Additionally, these conclusions may offer explanations for how performance changes when a deceptive intervention is implemented, but may not be effective explanations of the mechanisms responsible for why deception achieves this, or how participants accessed their metabolic reserve.

Despite the proposal that changes in pace due to the effects of deception may only be manifest in successive trials[9,10], Corbett et al.[11], Stone et al.[12] and Parry et al.[6] all found improvements in performance in the deception trials themselves. However, these studies used a computer projected image of an avatar or video footage of a road as oppose to a digital display of time or performance variables. Therefore the effects of a visual race environment or presence of a competitor may have had a mediating role between deception and the effect on performance[11]. With none of the studies measuring motivation or any other psychological variables, this suggestion warrants further validation.

The results of studies manipulating feedback continuously and discontinuously throughout exercise are inconsistent. Blind feedback, albeit inconsistently, neither affects nor hinders performance[13,47,48,53] therefore signifying that this form of manipulation may not be an appropriate methodology in the investigation of how an athlete's metabolic reserve can be accessed to improve performance. Similarly, the deception of external feedback has failed to produce changes in pacing strategy or performance when provided discontinuously or continuously where perception of performance is better than actual performance[6,13,32,52,53,59]. However, despite studies using varied methodologies when feedback is manipulated continuously causing perceptions of performance to be worse than actual performance, improvements in completion time, power output, time to exhaustion and magnitude of the end spurt have been found[6,12,32,59]. When considering that these studies likely have the same theoretical underpinnings, it is equivocal as to why the results are inconsistent, but it is clear that this line of deception research is of significant interest to future investigations with the potential to determine how deception can be used to facilitate performance. With a lack of investigation as to what mechanisms may be responsible, this future research also needs to elucidate the physiological and psychological factors involved.

3.4 Biofeedback

The effects of biofeedback deception on performance has been demonstrated in a study where participants were incorrectly informed of ambient and core temperatures during 30 minute cycling TT's[60]. In a deception trial, continuous visual feedback and discontinuous verbal feedback were manipulated so that participants perceived ambient and core temperatures to be lower than true values. As expected, distance covered in two trials in the heat was lower than in a temperate control trial; however this decrement in performance was ameliorated in the trial where the deception was employed. Changing the participants' beliefs of the expected task resulted in an alteration to the anticipatory RPE template, indicated by a lower RPE in the warm-up of the deception trial, consequently allowing for subtle increases in performance throughout the trial. This novel area of research warrants further investigation with substantial applicability to athletes performing at international competitions in varied environmental conditions.

3.5 Qualitative Performance Feedback

Most studies in the field of deception have manipulated participants' knowledge of the endpoint, distance or duration of the exercise and physiological variables such as intensity and speed, however studies manipulating qualitative performance feedback during running or cycling exercise have been less forthcoming[61–63]. Studies that have manipulated self-efficacy using false performance feedback have shown that higher task-specific self-efficacy is related to less anxiety[61] and more enjoyment of the exercise[63], than low self-efficacy groups. However, one study[62] found no effect on RPE or muscle pain intensity when self-efficacy was manipulated during moderate-intensity exercise, which supports the suggestion that the relationship between self-efficacy and perceived effort may be intensity-dependant[64]. A study by Stoate et al.[65] investigated whether feedback pertaining to the efficiency of performance during a running bout would influence movement efficiency. Lower oxygen uptake, more marked changes in perceptions of performance and greater positive affect were shown in the group that received positive fabricated feedback compared to a control group with no feedback. However this is in contrast to research that has shown that falsely enhancing perceptions of performance via feedback of physiological variables does not improve performance[6,10,13,32,52,53,59]. This suggests that the mechanisms by which feedback affects exercise performance may differ depending upon the type of deceptive feedback that is provided.

4 Ethical Considerations

The nature of deception studies infrequently conforms to ethical guidelines[66-69]. Deception may involve withholding information (e.g., exercise of an unknown duration), or deliberately misinforming participants of the true purpose and procedure of the study (e.g., false expectations of the exercise endpoint) to prevent a threat to the expectancy validity of the research. Therefore participants are not provided with full, comprehensive information as part of the informed consent process. In order to minimise the risk of psychological harm or distress that may be caused when there is an element of deception, care must be taken that the research is designed in a way to respect the participants' dignity and autonomy[66]. Deception should only be used if the study has strong scientific merit and is essential to the attainment of the required outcomes. At the earliest feasible opportunity, all participants should be fully debriefed as to how they were deceived and why the deception was necessary. Research to date has rarely detailed if, and how, this was addressed and the nature of the debrief provided. As the deception is deemed inappropriate if any discomfort, anger or objection is likely to be experienced when the deception is revealed[66], it is recommended that editors make an adequately detailed debrief process an essential element of deception studies in the future. Therefore, information pertaining to the responses of participants at debrief would be of interest as this may support the omission of some data or may provide anecdotal evidence for the deception being detected.

To ethically use deception with athletes as a training intervention whilst ensuring validity is not compromised, coaches could, for example, gain prior consent from athletes that some form of deception (such as inaccurate performance feedback, biofeedback or qualitative feedback) will be used in a subsequent training session over a given period. However, since the true nature of deception interventions should always be revealed to participants as soon as possible after being carried out and may have the possibility to incur negative effects if exposed to frequently, deception may not always be a viable training or competitive intervention.

5 Conclusion

Research involving deception has implemented complex designs and varied methodologies, making it difficult to draw any definitive conclusions about how pacing strategy and performance are affected by deception. Many studies have used deception to investigate the theoretical underpinnings of pacing and performance, with a large focus on the prevalence of teleoanticipation. While a few studies have demonstrated that deception can be used to enhance performance, the value of such findings has been in demonstrating the existence of an exercise reserve.

There are a number of ways in which deception interventions have been designed, each intending to gain particular insights into pacing behaviour and performance. Deception methodologies can be conceptualised according to a number of dimensions such as deception timing (prior to or during exercise); presentation frequency (blind, discontinuous or continuous); and type of deception (performance - distance, time, speed, power, cadence; biofeedback - heart rate, temperature etc.; environmental feedback - gradient, competitor, temperature etc.). Studies that deceive participants prior to exercise may provide insights about the role of information on anticipatory pacing. Deceptions that are made during exercise, either in continuous or discontinuous form, have revealed more about the influence of information on on-going adjustments to pace. Most studies have deceived participants about their performance, and few have used biofeedback or environmental manipulations. Most environmental interventions have manipulated the exercise duration, with a few focusing on competitor behaviour or optic flow. Studies using exercise of fixed-duration or fixed-intensity or exercise of an unknown duration, or blinding participants to all feedback have aimed to assess central mechanisms but lack ecological validity to competitive performance. Often, untrained participants have also been used who are unaccustomed to the exercise and have no previous experience or pacing schemas, which may limit our understanding of how trained athletes respond to deception interventions. Scope for further research using these designs and participants may have some theoretical value but are the key questions in deceptive research not more practical than just theory, with the overall aim of ascertaining how deception can be used to enhance athletic performance? Therefore, from the findings that have been reviewed in this paper, it is recommended that future studies investigate how deception of continuous visual feedback, environmental manipulation, qualitative performance feedback and biofeedback can be used in ecologically valid competitive performances with trained athletes.

In addition to a more thorough deliberation of research design, the variables measured should also be an equally considered factor of future research. Psychological variables are often thought to play a key role in mediating the performance outcome in deception studies, however, this has often been poorly conceptualised (e.g., discussing motivation in general terms without specific consideration of how motivation may specifically play a role) or operationalized in the adopted methods (e.g., limited measurement of key psychological states). Future research needs to include psychological measures, such as affect, attentional focus, emotions and motivation, in addition to physiological measures, if we are to further our understanding of these mechanisms and determine what types of deception could be best used to improve performance.

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