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Images depicting human pain increase exercise-induced pain and impair endurance cycling performance

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Abstract

Observing others in pain can enhance pain intensity. The current study aimed to investigate whether viewing images of others in pain influences exercise-induced pain (EIP) and endurance cycling performance. Twenty-one recreational cyclists attended five laboratory visits. The first two visits involved the measurement of participants' maximal aerobic capacity and familiarized participants to the fixed power (FP) and 16.1 km cycling time trial (TT) tasks. The FP task required participants to cycle at 70% of their maximal aerobic power for 10-minutes. In the subsequent three visits, participants performed the FP and TT tasks after viewing pleasant, painful or neutral images. Participants rated the subset of painful images as significantly more painful than the pleasant and neutral images; with no difference in the pain ratings of the pleasant and neutral images. In the FP task, ratings of EIP were higher in the painful image condition compared to the pleasant condition, while no differences in EIP were observed between the pleasant and neutral conditions or the neutral and painful conditions. Perceived exertion, heart rate (HR) and blood lactate (B[La]) during the FP task did not differ across conditions. In the TT, performance did not differ between the pleasant and neutral conditions. However, TT performance was reduced after viewing painful images compared to neutral or pleasant images. Despite these performance changes, heart rate HR, B[La], perceived exertion and EIP did not differ between the three conditions. These results suggest that viewing painful images prior to exercise decreases TT performance and increases pain during a fixed intensity exercise task.

Key Words: Exercise-induced pain; compassional hyperalgesia; time trial; performance; empathy.

Abbreviations

EIP	Exercise Induced Pain
FP	Fixed Power
TT	Time Trial
HR	Heart Rate
B[La]	Blood Lactate
RPE	Rating of Perceived Exertion
IAPS	International Affective Picture System
PO	Power Output

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Intense exercise causes a noxious environment in the muscle which typically elicits exercise-induced pain (EIP) (Dannecker & Koltyn, 2014). Tolerance of this sensation has been associated with performance in endurance exercise tasks, with those better able to tolerate EIP producing superior performance (Astokorki & Mauger, 2016). Indeed, the experimental manipulation of EIP has been shown to affect exercise performance. For example, acetaminophen and caffeine have both been shown to reduce EIP and increase endurance cycling performance (Gonglach, Ade, Bemben, Larson, & Black, 2015; Mauger, Jones, & Williams, 2010). Based on this evidence, it is suggested that pain may act as a regulator of work rate during endurance exercise tasks, influencing the athlete's ability to access a physiological reserve (Noakes, 2011; Swart et al., 2009). While these interventions aimed at decreasing EIP have resulted in improvements in performance, interventions that instead increase EIP may provide novel insights into the role of pain as a regulator of endurance exercise performance.

Viewing others in pain has been shown to induce the vicarious experience of pain in the observer, termed *"synaesthesia for pain"* (Fitzgibbon, Giummarra, Georgiou-Karistianis, Enticott, & Bradshaw, 2010), and increase one's sensitivity to pain (Godinho et al., 2012; Khatibi, Vachon-Presseau, Schrooten, Vlaeyen, & Rainville, 2014; Loggia, Mogil, & Bushnell, 2008). This psychophysical phenomenon, whereby pain sensitivity is increased when viewing others in pain, is also referred to as *compassional hyperalgesia* and has been observed in both men and women (Godinho et al., 2012). Loggia et al. (2008) reported that when participants observed videos of others in pain, they offered higher pain intensity and pain unpleasantness ratings in response to noxious thermal stimuli. These changes in pain sensitivity go beyond the induction of a negative affective state, with research showing stronger hyperalgesic effects when unpleasant images containing human pain are presented (Godinho, Magnin, Frot, Perchet, & Garcia-Larrea, 2006). In fact, neuroimaging studies report that brain areas associated with the affective-motivational component of pain, such as the anterior cingulate cortex, are also activated when viewing others in pain (Jackson, Rainville, & Decety, 2006). If applied in an exercise setting, viewing images of others in pain presents as a potential model for the manipulation of pain experienced during endurance exercise.

However, the hyperalgesia experienced after viewing others in pain is yet to be explored in exercise-induced pain. Therefore, it remains unclear as to whether viewing others in pain impacts on exercise-induced pain and, by extension, influences endurance exercise performance. The purpose of this study was to examine whether viewing images of others in pain can increase the intensity of pain experienced during endurance exercise and impact on exercise performance. It was hypothesised that images depicting others in pain would induce hyperalgesia during exercise at a fixed intensity and reduce endurance cycling time trial (TT) performance.

Methods

Participants

Sample size estimation was conducted using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007), based on data reported in two studies. First, an effect size of 0.74 was used based on the difference in cycling TT performance reported by Mauger et al. (2010) following the administration of acetaminophen. A sample size of 6 was estimated to have 80% power ($\alpha = 0.05$) to detect an effect of this size. Given the differences in the method of pain manipulation and participant characteristics between the current study and that of Mauger et al. (2010), we conducted a second sample size estimation based on an effect size of 0.34, calculated from the findings of Godinho et al. (2012) who reported hyperalgesic effects of observing images of human pain. This calculation resulted in an estimated minimum sample of 17 participants required to detect an effect with 80% power ($\alpha = 0.05$).

Due to the large effect sizes observed in both studies, we sought to recruit a larger sample than the minimum calculated. Therefore, 21 male (n = 13) and female (n = 8) recreational cyclists (>3 h exercise per week) were recruited for participation (see Table 1). The participation opportunity was advertised using flyers distributed throughout the local community and university. Recruitment also occurred online, through social media platforms. Volunteers were encouraged to contact the primary researcher to register their interest in participating.

Participants were given an overview of the study, describing the requirements for their involvement. Specifically, participants were informed that a series of potentially distressing images would be viewed to examine the effects on exercise performance. In order to reduce the possibility of response bias, participants were not informed of the hypothesised effects of the intervention on pain and performance. The participants were aware that all data would be unidentifiable and that they had the right to withdraw from the study at any time. Following this, they were asked to complete the inclusion/exclusion criteria checklist and then asked to sign an informed consent form. Individuals were excluded if they self-reported any of the following: pregnancy; lifetime history of psychological disorders; history of fainting; bleeding disorders (e.g. haemophilia); types I or II diabetes; lifetime history of clinically significant or unstable medical, neuropsychiatric, or chronic pain disorders; history of substance abuse or dependence; history of brain disorders, surgery, tumour or heart disease;

intracranial metal implantation; chronic use of medications that affect the central nervous system. Participants were asked to avoid vigorous exercise 24 hours before the laboratory visits, and to refrain from the ingestion of alcohol, caffeine and analgesics 48 h, 8 h and 6 h before any experimental visit. The experimental protocol was approved by the local Ethics Committee.

Procedure

The study followed a within groups, randomised and counterbalanced design, including three experimental conditions (painful, neutral, pleasant). Participants reported to the laboratory on five separate occasions, with each session separated by 2-5 days. The ordering of experimental conditions was randomised by a researcher not otherwise involved in the study. An online tool was used to achieve this randomisation (https://www.randomizer.org/).

Session 1. Participants were first given standard instructions for the use of the numeric pain rating scale (Cook, O'Connor, Eubanks, Smith, & Lee, 1997) and rating of perceived exertion (RPE) scale (Borg, 1998) to be used throughout all physical performance measures. To gain an understanding of participants' aerobic capacity, a cycling-based incremental ramp test was then conducted. After a 5 min warm-up at 75 Watts, the incremental ramp protocol started at 100 Watts and increased by 30 Watts every 2 min until volitional exhaustion or when cadence dropped 5 RPM below the participants' self-selected cadence (Astokorki & Mauger, 2016). Throughout the test and all subsequent cycling tasks, power output (PO) was monitored using a cycle ergometer (Velotron, Racermate, Seattle, WA) and heart rate (HR) was continuously displayed using a Polar Vantage XL HR monitor (Polar Electro Oy, Kempele, Finland). Pain intensity and perceived exertion were recorded 15 s before the end of each 2 min stage. Prior to the test, the ergometer was adjusted for each participant and the setting was recorded to allow reproduction at each subsequent visit for both the fixed power (FP) and TT tasks. Expired gases were assessed using an online gas analyser (Cortex Biophysik GmbH, Leipzig, Germany) throughout the test. Following a rest period of 30 min, participants then performed a familiarisation of the FP (see FP Procedure) and TT (see TT Procedure) tests to be used in subsequent sessions. A 5 min rest period separated the FP and TT tasks.

Session 2. The purpose of the second session was to again familiarise participants to the exercise performance tasks. Specifically, participants attended the laboratory and first completed the FP task. During this familiarisation session, self-selected cadence was monitored to allow for this cadence to be replicated across the subsequent experimental sessions. Following a 5 min rest period, the TT was completed.

Sessions 3-5. Sessions 3-5 formed the experimental data collection phase of the study. In these sessions, participants first sat quietly for 10 min before viewing 15 either painful, neutral or pleasant images (see Images Procedure), depending on their assigned condition. Immediately after viewing the images, participants were positioned on the cycling ergometer and instructed to complete the FP task. After a 5 min rest period, during which time participants viewed a further 10 painful, neutral or pleasant images, the TT was completed. To reduce the risk of bias, the experimenter involved in the collection of performance and pain data during the FP and TT tasks was not present during the presentation of images. This ensured that they were blinded to the participants' assigned condition.

At the completion of the TT in the final session, participants were thanked for their involvement and invited to ask any questions that they had about the study.

Measures

EIP. Pain experienced during the cycling tasks was assessed using the scale developed by Cook et al. (1997). This scale required participants to verbally report their perceived pain levels according to a 12-point scale. Standardised instructions (see Cook et al., 2004) were provided to participants to before each cycling task to ensure proper use of the scale. Importantly, participants were asked to rate the feelings of pain and discomfort experienced in the legs and not use the rating as an expression of perceived exertion.

Perceived exertion. Perceived exertion was assessed using Borg's (1998) 6-20 RPE scale. Prior to each cycling task, participants were asked to report their perceived exertion as the amount of effort required to drive the limbs.

FP procedure. Prior research has shown that during self-paced exercise tasks (e.g. a TT), participants alter their work rate to maintain a fixed progression in perceptual parameters (Mauger, 2014; Tucker, 2009). Therefore, an FP task was used to examine potential changes in pain, perceived exertion, and physiological parameters of HR and blood lactate concentration (B[La]) when cycling at a fixed PO, across the three experimental conditions. The task required participants to cycle at a fixed power equivalent to 70% of their maximal aerobic power (determined in the incremental ramp task) for 10 min. A fingertip sample of blood was collected at rest, 5 min and 10 min during the FP task for the analysis of B[La]. Pain, perceived exertion and HR were assessed at 2 min intervals throughout the FP task. Scripted verbal encouragement was provided throughout.

TT procedure. In the TT, participants were instructed to complete a 16.1 km cycling TT on the cycle ergometer (Veltron, Racermate, Seattle, WA), as previously described (Mauger et al. 2010). During the self-paced TT, perceived exertion and pain were assessed every km, using the scales described above. HR was also measured at the end of each km of the TT. Every 4 km, a fingertip sample of blood was taken to assess B[La] concentration. To ensure consistency across sessions and participants, scripted verbal encouragement was offered throughout the TT. At the completion of the 16.1 km, participants completed a 10 min cool-down at a self-selected intensity.

Images procedure. Seventy-five images were categorised into three subsets (painful, pleasant and neutral). The painful images subset (*n* = 25) included images of athletes in pain (e.g. suffering a severe injury), while the pleasant images subset (*n* = 25) showed athletes enjoying cycling, exercising or in enjoyable situations. The neutral subset of images (*n* = 25) included complex visual stimuli with no overtly emotional content (e.g. a natural scene). Where possible, images (40%) were taken from the International Affective Picture System (IAPS), with IAPS arousal and valence values used to categorise images into the painful, pleasant and neutral subsets (Lang, Bradley, & Cuthbert, 1997) (see Supplementary material for image codes). As a limited number of relevant images (i.e. pain occurring in sporting situations) were present on the IAPS database, the remaining images were obtained from the internet (images available upon request).

Images were presented to participants in a PowerPoint presentation, following protocols described elsewhere (Boggio, Zaghi, & Fregni, 2009; Godinho et al., 2012). Briefly, participants viewed a computer screen at a comfortable distance of approximately 60 cm. A standardised set of instructions were used to explain the procedure of the study, and participants were informed that a series of images would be viewed. The three subsets of images were presented on separate visits in a counterbalanced and randomised order. Each subset presented a total of 25 images (15 images were viewed before the FP test and 10 images before the TT). Each image was viewed for 30 s. After viewing the image for 25 s, participants were asked to provide a rating of their pain affect in response to the question “how do you feel while viewing the image?” (1 = comfortable/no pain, 9 =

uncomfortable/pain) (Boggio et al., 2009). The number of images and duration of presentation were selected to produce an overall time-on-task, including an opportunity to provide a pain affect rating, that was approximately consistent with previous research (Boggio et al., 2009). The ordering of the images within each subset was kept consistent across participants.

Statistical Analysis

Prior to statistical analysis, assumptions were checked for each statistical test. Data relating to completion time for the TT violated the assumption of normality. The reciprocal transformation was used to normalise the distribution of TT completion time data, which was then analysed using a repeated measures analysis of variance (ANOVA), with the factor of Condition (painful, neutral, pleasant). Pairwise comparisons with a Bonferroni correction were used to follow up significant differences in TT completion time across conditions. The same analyses were also conducted using non-transformed data, giving the same results. Therefore, to aid in interpretation, results presented here relate to the analysis of non-transformed TT completion time data.

In cases where the assumption of sphericity was violated, the Greenhouse-Geisser epsilon was corrected. Mean ratings of pain affect for image subsets were analysed using a repeated measures ANOVA with the factor of Condition (painful, neutral, pleasant), and pairwise comparisons with a Bonferroni correction were used to further investigate significant main effects across the three levels. HR (beats per minute (bpm)), RPE and EIP during the FP task were analysed using 3 (Condition: painful, neutral, pleasant) × 5 (Time: 2 min, 4 min, 6 min, 8 min, 10 min) repeated measures ANOVAs. A 3 (Condition: painful, neutral, pleasant) × 3 (Time: rest, 5 min, 10 min) ANOVA was used to analyse B[La] measured during the FP task. For the TT task, PO, HR, RPE and EIP were analysed using 3

(Condition: painful, neutral, pleasant) × 16 (Distance: 1km, 2km, 3km, 4km, 5km, 6km, 7km, 8km, 9km, 10km, 11km, 12km) repeated measures ANOVAs.. B[La] during the TT task was analysed using a 3 (Condition: painful, neutral, pleasant) × 4 (Distance: 4km, 8km, 12km, 16km) repeated measures ANOVA. Appropriate follow-up pairwise comparisons with Bonferroni corrections were used to further investigate significant main effects on the Condition factor.

Statistical analysis was performed using the statistical package SPSS version 22 for Windows programs (SPSS Inc., Chicago, IL, USA). Descriptive data are reported as means ± SD. Statistical significance was accepted when $p < 0.05$. Cohen's *d* and partial eta squared (η_p^2) are reported as estimates of the effect size.

Results

Image Ratings

Ratings of pain affect differed across the three experimental conditions, F (1.105, 22.094) = 257.87, p = .000, η_p^2 = .928 (Figure 1). Specifically, participants provided significantly higher pain affect ratings for the subset of painful images (6.061 ± 1.301) compared to both the pleasant images (1.248 ± 0.303, p = .000, d = 5.095) and neutral images (1.328 ± 0.401, p = .000, d = 4.917). No significant difference was observed between pain affect ratings of the pleasant and neutral images (p = .929, d = .225).

FP Task

HR. Mean HR in the FP task did not differ across the conditions, F (2, 40) = .360, p = .700, η_p^2 = .018. There was a main effect for Time, F (1.740, 34.798) = 79.521, p = 000, η_p^2 = .799, but no significant interaction effect during the FP test, F (8, 160) = .781, p = .620, η_p^2 = .038. See Table 2 and Figure 2a for data on HR during the FP task.

B[La]. No significant main effect of Condition was observed for B[La] during the FP task, *F* (2, 40) = 1.927, *p* = .159, η_p^2 = .088. There was a main effect for Time, *F* (1.288, 25.761) = 58.435, *p* = .000, η_p^2 = .745, but no significant interaction effect was found, *F* (4, 80) = 1.270, *p* = .289, η_p^2 = .060. See Table 2 and Figure 2b for data on B[La] during the FP task.

Perceived exertion. No significant main effect of Condition was observed for perceived exertion in the FP task, *F* (2, 40) = 2.788, *p* = .074, η_p^2 = .122. There was a main effect for Time, *F* (1.154, 23.079) = 32.688, *p* = .000, η_p^2 = .620, but no significant interaction effect was found, *F* (3.594, 71.874) = .856, *p* = .485, η_p^2 = .041. See Table 2 and Figure 2c for data on perceived exertion during the FP task.

EIP. There was a main effect of Condition for EIP, *F* (2, 40) = 4.363, *p* = .019, η_p^2 = .179. Pairwise comparisons with a Bonferroni correction showed a significant difference in EIP between the pleasant and painful image conditions (*p* = .033, *d* = .263). No significant difference between the pleasant and neutral image conditions (*p* = 1.00, *d* = .062), or between the neutral and painful image conditions was found (*p* = .232, *d* = .206). There was a significant main effect for Time, *F* (1.290, 25.808) = 30.606, *p* = .000, η_p^2 = .605, but no significant interaction effect for EIP, *F* (3.834, 76.674) = .805, *p* = .521, η_p^2 =.039. See Table 2 and Figure 2d for data on EIP during the FP task.

TT Task

Completion time. The completion time for the TT differed across conditions, *F* (2, 40) = 9.223, *p* = 0.001, η_p^2 = .316. Pairwise comparisons revealed that participants performed a significantly faster TT in the pleasant condition (29 min 38 s ± 4 min 35 s; *p* = .005, *d* = .140) and the neutral condition (29 min 39 s ± 3 min 34 s; *p* = .009, *d* = .136) compared to the painful condition (30 min 19 s ± 5 min 7 s). There was no significant difference in TT completion time between the neutral condition and the pleasant condition (*p* = 1.000, *d* = .004).

PO. Mean PO in the TT differed across the three conditions, *F* (2, 40) = 5.536, *p* = .008, η_p^2 = 2.17) (Figure 3a). Pairwise comparisons employing a Bonferroni correction showed a significantly higher PO in the pleasant condition (209.236 Watts ± 68.980 Watts; *p* = .007, *d* = .131) and the neutral condition (207.633 Watts ± 63.956; *p* = .024, *d* = .112) compared to the painful condition (200.218 Watts ± 68.392 Watts). There was no significant difference between the neutral and pleasant conditions (*p* = 1.000, *d* = .024). There was also a main effect for Distance, *F* (3.160, 63.195) = 11.283, *p* = .000, η_p^2 = .361, but no interaction effect between Condition and Distance was found, *F* (30, 600) = .847, *p* = .702, η_p^2 = .041, shown in Figure 3b.

B[La]. The ANOVA revealed a significant main effect of Condition for B[La] during the TT, *F* (2, 40) = 5.724, *p* = .007, η_p^2 = .223. Pairwise comparisons employing a Bonferroni correction showed no significant difference in mean B[La] between pleasant and painful image conditions (*p* = .145, *d* = .556). There was also no significant difference between the pleasant and neutral image conditions (*p* = 1.000, *d* = .194), or between the neutral and painful image conditions (*p* = .113, *d* = .454). There was a main effect for Distance, *F* (1.505, 30.103) = 20.332, *p* = .000, η_p^2 = .504, but no significant interaction effect was found, *F* (3.219, 64.374) = 1.961, *p* = .125, η_p^2 = .089. See Table 3 and Figure 4a for data on B[La] during the TT.

HR. A significant difference in the mean HR between conditions during the TT was observed, *F* (2, 40) = 4.502, *p* = .017, η_p^2 = .184. However, pairwise comparisons employing a Bonferroni correction uncovered no significant difference in HR between the pleasant and neutral conditions ($p = 1.00$, $d = .088$), the pleasant and painful conditions ($p = .095$, $d = .408$), nor the painful and neutral conditions ($p = .170$, $d = .292$) . There was a significant main effect for Distance, F (2.392, 47.849) = 43.410, $p = .000$, $\eta_p^2 = .685$, but no significant interaction effect was found, F (30, 600) = .572, $p = .969$, $\eta_p^2 = .028$ See Table 3 and Figure 4b for data on HR during the TT.

Perceived exertion. No significant differences in RPE were observed across the three conditions, F (2, 40) = .249, $p = .781$, $\eta_p^2 = .012$. However, there was a main effect for Distance, F (1.840, 36.793) = 92.197, $p = .000$, $\eta_p^2 = .822$, but no significant interaction effect, F (30, 600) = 1.344, $p = .106$, $\eta_p^2 = .063$. See Table 3 and Figure 4c for data on perceived exertion during the TT.

EIP. Pain experienced during the TT did not differ across conditions, F (2, 40) = 1.865, $p = .168$, $\eta_p^2 = .085$. Irrespective of condition, pain did change throughout the TT, F (1.511, 30.220) = 89.387, $p = .000$, $\eta_p^2 = .817$, but no significant Distance by Condition interaction effect was found, F (30, 600) = 1.380, $p = .088$, $\eta_p^2 = .065$. See Table 3 and Figure 4d for data on EIP during the TT.

Discussion

Pain experienced during exercise is thought to have an impact on endurance exercise performance (Mauger, 2014). In support, factors that attenuate EIP have been shown to enhance exercise performance (Mauger et al., 2010). It is, therefore, possible that endurance exercise performance may be negatively impacted by factors that increase the pain of exercise. Compassional hyperalgesia is a phenomenon whereby the observation of pain in others results in increased pain sensitivity, typically assessed through pain intensity ratings given on a numerical rating scale (Godinho et al., 2012). Therefore, the current study aimed to assess whether viewing images of others in pain impacts on EIP and endurance cycling performance. It was hypothesised that images of others in pain, presented immediately before exercise, would increase perceived pain during exercise and reduce exercise performance. This hypothesis was partially supported, with results indicating that pain experienced during an exercise task, which required participants to cycle at a fixed PO, was elevated after viewing images of other athletes in pain compared with viewing pleasant images. Also, as hypothesised, viewing images of others in pain resulted in longer time-to-completion and lower PO in a cycling TT.

The observed change in perceived pain intensity resulting from viewing others in pain aligns with the compassional hyperalgesic effect (Godinho et al., 2012). Indeed, the hyperalgesic effect of viewing others in pain has been consistently observed across a range of pain modalities, including acute thermally-induced pain (Loggia et al., 2008) and noxious electrical stimulation (Godinho et al., 2012; Godinho et al., 2006; Khatibi et al., 2014; Mailhot, Vachon-Presseau, Jackson, & Rainville, 2012). However, the current findings are novel as they are the first to describe how the perceived intensity of EIP can also be subject to manipulation by observing others in pain. This is an important advancement on existing knowledge, as it has been suggested that EIP represents a distinct psychophysiological experience to that of pain induced through other experimental methods (Angius, Hopker, Marcora, & Mauger, 2015).

The use of the FP task in the current study presents as an important methodological consideration in the assessment of changes in EIP. The FP test was designed to assess whether the intervention resulted in a change in perceptual response (i.e. pain and RPE) for a given exercise intensity. The subsequent TT was then performed to assess whether the intervention would elicit a change in endurance performance. This experimental design was necessary to fully explore the research question, because it has previously been shown that whilst changes in perceptual responses to an intervention can be observed in fixed intensity exercise, in self-paced endurance exercise (such as a TT), participants tend to maintain a fixed progression in perceptual parameters at the expense of changes to work rate (Mauger, 2014; Mauger et al., 2010; Tucker, 2009). Thus, in the current study, the TT provided a true measure of self-paced endurance performance, whilst the FP task helped demonstrate that the intervention elicited changes in EIP intensity. Importantly, both tasks induced levels of pain that were consistent with the EIP reported in previous research involving similar maximal and submaximal cycling tasks (Astokorki & Mauger, 2017; Astorino, Cottrell, Talhami Lozano, Aburto-Pratt, & Duhon, 2012; Mauger et al., 2010; Motl, Gliottoni, & Scott, 2007). Future research attempting to explore the role of pain in the regulation of endurance exercise performance should consider implementing a similar methodological approach as that used here. Indeed, in an editorial by Hettinga et al. (2017), it is suggested that the use of both FP and TT tasks may be required to provide a comprehensive understanding of the regulation of endurance performance.

In addition to the changes in EIP observed in the FP task, viewing images of others in pain also reduced performance in the 16.1 km cycling TT. These changes in performance occurred without any change in pain experienced during the TT. These findings can be interpreted in the context of the observed increases in performance following the administration of analgesic substances. For example, Mauger et al. (2010) reported increased performance in a cycling TT without changes in perceived pain after the administration of acetaminophen; a finding subsequently replicated in repeated sprint cycling (Foster, Taylor, Chrismas, Watkins, & Mauger, 2014), running (Pagotto, Paradisis, Maridaki, Papavassiliou, & Zacharogiannis, 2018) and isometric contractions (Morgan, Bowtell, Vanhatalo, Jones, &

Bailey, 2018). Similarly, the analgesic effect of caffeine consumption has been shown to produce performance improvements in a cycling task (Gonglach et al., 2015). Together, these findings provide indirect support for the putative role for pain in the regulation of work-rate during exercise tasks.

Whilst it is tempting to attribute the observed increase in EIP during the FP task and subsequent changes in TT performance to compassional hyperalgesia, alternative explanations should be carefully considered. Research exploring compassional hyperalgesia has offered greater insight into the phenomenon, suggesting a more complex interpretation of the current findings may be warranted. In particular, the hyperalgesia experienced after viewing others in pain appears to be dependent on an empathic response being elicited in the observer. After experimentally manipulating the degree of empathy that an observer feels for an actor, Loggia et al. (2008) found that those with higher empathy for an actor appearing to be in pain, displayed stronger compassional hyperalgesia. Similarly, dispositional optimism has also been shown to correlate with compassional hyperalgesia, with highly empathic individuals showing strong hyperalgesic responses to observing others in pain (Mailhot et al., 2012). In fact, those scoring lowest on dispositional optimism experienced *reduced* pain sensitivity (i.e. analgesia) as a result of viewing pain in others. Without a measure of empathy, we cannot conclude as to whether participants in the current study empathised with those depicted in the painful images. As a consequence, the observed changes in EIP cannot be conclusively attributed to compassional hyperalgesia.

Alternative explanations for the current findings should, therefore, be considered. One potential explanation relates to the likely impact of the painful and pleasant images on affect. Previous research has reported that the induction of a positive affective state decreases pain sensitivity, while negative affect results in increased pain sensitivity (Meagher, Arnau, &

Rhudy, 2001; Meng et al., 2012; Zelman, Howland, Nichols, & Cleeland, 1991). These findings support motivational priming theory, which describes how the activation of an appetitive or aversive motivational state can enhance the amplitude of responses to the subsequent presentation of congruent stimuli (Lang, 1995). Therefore, it is possible that the change in pain evoked by the presentation of painful images was due to the induction of negative affect and the activation of an aversive motivational drive. Similarly, it is possible that the pleasant images induced an appetitive motivational state which decreased EIP in the FP task relative to the painful condition. Without an assessment of the valence dimension of affect, it is beyond the scope of the current study to partition the possible effects of motivational priming and compassional hyperalgesia. This presents as a notable limitation of the current study. We do, therefore, encourage future research to measure changes in affect resulting from experimental manipulations so as to allow for the application of motivational priming theory to exercise performance settings.

In addition to the likely influence of the image intervention on affect, the current findings may be explained by a mental fatigue or ego depletion effect. A recent meta-analysis by Giboin and Wolff (2019) reported impaired endurance performance after the induction of a mentally fatigued or ego depleted state. This state is typically achieved through prior mental exertion in a challenging cognitive task (e.g. Stroop test) and is thought to impair subsequent performance by elevating perceived exertion (Marcora, Staiano, & Manning, 2009). In the current study, no such change in perceived exertion was observed in the FP task, suggesting that the observed decrement in TT performance was not due to the induction of mental fatigue or ego depletion. Also, without a measure of mental fatigue or ego depletion, it is unclear whether the images presented in the painful image condition induced such as state. Indeed, issues with operationally defining mental fatigue and ego depletion (Lurquin &

Miyake, 2017) and the failure to replicate the phenomena (Hagger et al., 2016), highlight the need for additional research into these constructs.

Ratings of perceived exertion during the FP and TT tasks were similar to those reported in previous research (Mauger et al., 2010; Williams et al., 2015). However, it is noteworthy that the intervention resulted in no changes to perceived exertion but a significant change to EIP in the FP task. This provides further evidence that EIP and perceived exertion can be separated, provided participants are given adequate instruction and familiarisation with the two scales (Pageaux, 2016). Of further note, is that despite no apparent effect of the intervention on perceived exertion, performance of the TT was affected by the image intervention. This supports the argument that endurance performance can be moderated without any change in perceived exertion. Such findings question the emphasis placed on perceived exertion as the sole perceptual regulator of work-rate during endurance exercise, as proposed by the psycho-biological model (Marcora, 2008). Indeed, the current findings fail to support Staiano, Bosio, de Morree, Rampinini, and Marcora (2018) and their suggestion that EIP may influence exercise performance indirectly, by altering perceived exertion.

It is noteworthy that no differences in EIP and cycling TT performance were observed between the pleasant and neutral image conditions. The lack of a performance improvement in the pleasant condition is inconsistent with previous research reporting increases in cycling performance following the induction of pleasant affective states using IAPS images (Coudrat et al., 2014; Jaafar et al., 2015). However, more recent research by di Fronso et al. (2020) suggests a more complex effect, with some participants showing performance improvements after viewing pleasant images and others displaying improved performance after unpleasant images. Whether these individual differences in responses to the pleasant images were also evident in the findings presented above is beyond the scope of the current study. However, given the likely affective consequences of the images used in the current study, the lack of a measure of affect presents as a potential limitation. As suggested above, future research should extend on the current findings by including measures of affect.

Several other limitations should be considered when interpreting the current findings. First, the current study recruited male and female recreational cyclists. It is possible that the findings reported here may not generalise to other populations. For example, athletes and non-athletes have been shown to exhibit differences in their pain responses (Flood, Waddington, Thompson, & Cathcart, 2016; Tesarz, Schuster, Hartmann, Gerhardt, & Eich, 2012). Similarly, research has reported differences in the pain responses of contact and non-contact athletes (Ryan & Kovacic, 1966), strength and endurance athletes (Assa, Geva, Zarkh, & Defrin, 2019) and males and females (Greenspan et al., 2007). While it is beyond the scope of the current study to compare the effect of images depicting human pain across these sample populations, the limits to the generalisability of the current findings should be acknowledged and explored in future research. Sex-related differences, in particular, should be addressed given the observed differences in pain responses to the presentation of IAPS images between men and women (Meagher et al., 2001).

In the current study, the three experimental conditions were presented in a randomised order. A single blinded design was also used, with the primary researcher unaware of the assigned image condition. To further reduce the potential for bias, researchers used standardised instructions for the presentation of the pain and perceived exertion measures and provided scripted verbal encouragement throughout the FP and TT tasks. However, the nature of the intervention made it impossible to blind the participants to their assigned order of conditions. Therefore, it is possible that participants were biased in their responses. We encourage future research to address this potential limitation through alternative methodological approaches, such as the use of subliminal priming, as used by Godinho et al. (2012).

Participants provided higher pain affect ratings in response to the images presented in the painful condition compared to the neutral and pleasant conditions. The measure used to assess responses to the images matched that used by Boggio et al. (2009) to determine the emotional pain and discomfort experienced after viewing images of others in pain. While responses to this measure indicated increased pain affect in the pain condition, alternative measures should be considered in future research. In particular, pain affect is widely assessed using pain unpleasantness numerical rating scales (Rainville, 2002) and multidimensional tools such as the McGill Pain Questionnaire (Melzack, 1987).

Conclusion

In the current study, viewing images of others in pain increased the pain experienced during a cycling task of fixed intensity and decreased exercise performance in a cycling TT. These findings have significant implications for our understanding of the role of pain in exercise performance, indicating that factors that produce hyperalgesic effects, such as viewing pain in others, can be detrimental to performance in fatiguing exercise.

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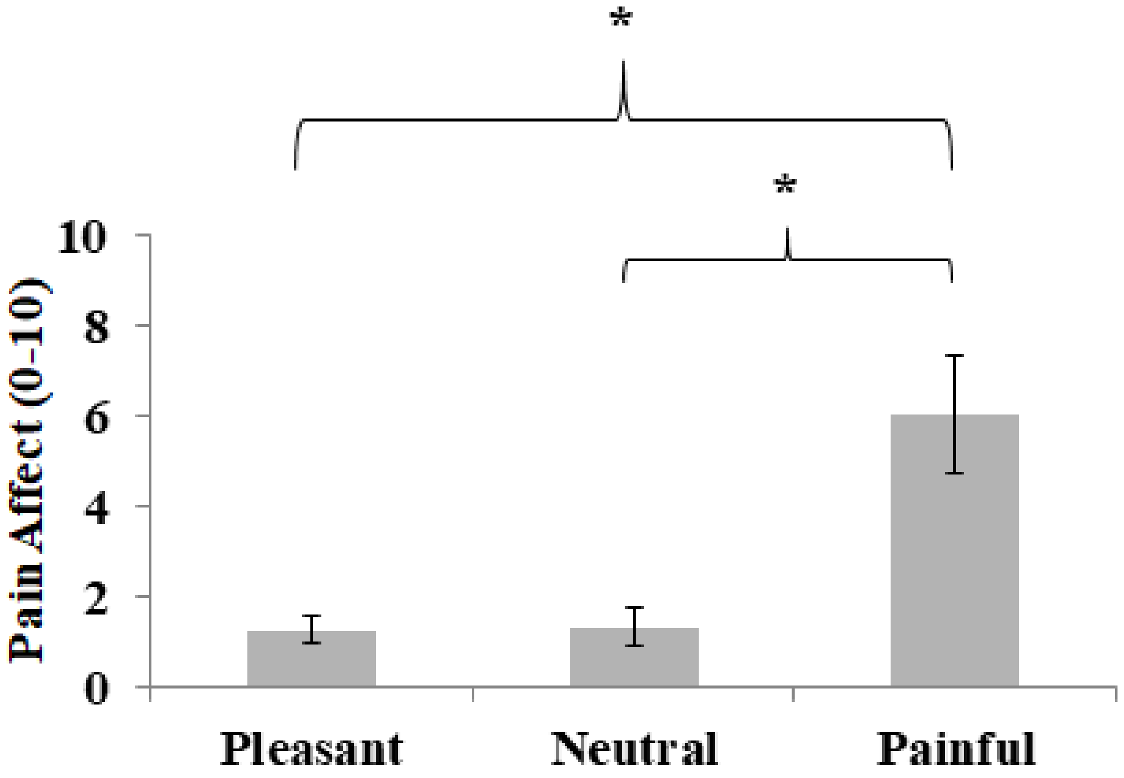
Figure Captions

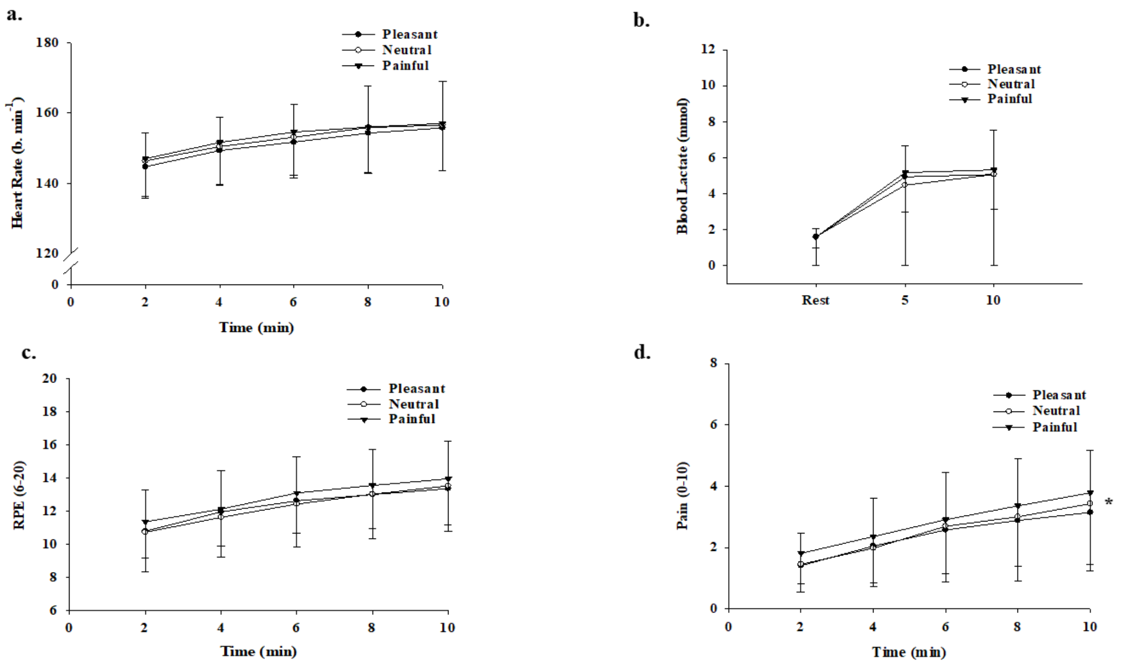
Figure 1. Differences in pain affect while viewing images in the painful, neutral and pleasant conditions. * denotes significant difference between conditions.

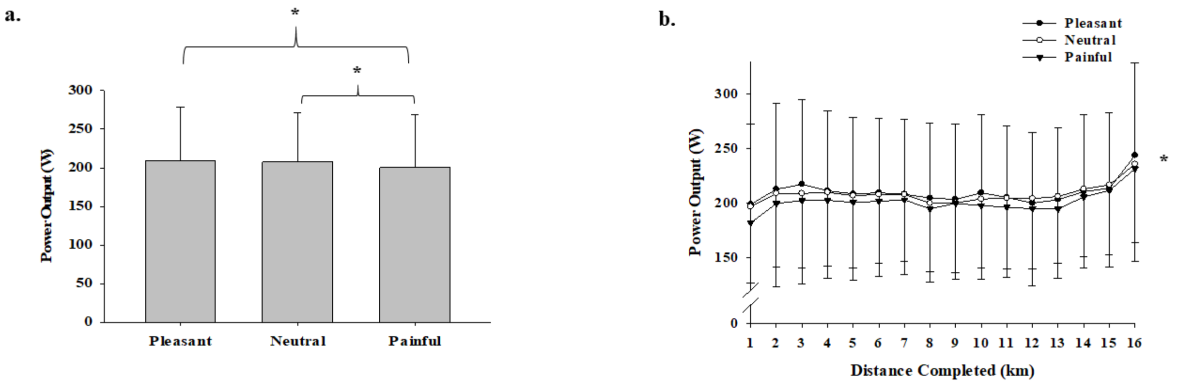
Figure 2. Physiological and perceptual measures taken during the fixed power (FP) cycling task. Panel A shows differences in heart rate between conditions over time. Panel B shows differences in blood lactate between conditions over time. Panel C shows differences in ratings of perceived exertion (RPE) between conditions over time. Panel D shows differences in pain between conditions over time. * denotes a significant difference in mean pain across the FP task between the pleasant and painful conditions.

Figure 3. Time trial (TT) performance across the painful, neutral and pleasant conditions. Panel A shows differences in power output during the TT between the three conditions. Panel B shows differences in power output between conditions over the distance of the TT. * denotes a significant difference in power output in the TT between the painful and pleasant conditions and the painful and neutral conditions.

Figure 4. Physiological and perceptual measures taken during the cycling TT task. Panel A shows differences in blood lactate between conditions throughout the TT. Panel B shows differences in heart rate between conditions throughout the TT. Panel C shows differences in RPE between conditions throughout the TT. Panel D shows differences in pain between conditions throughout the TT. # denotes a significant main effect of Condition for blood lactate during the TT. * denotes a significant main effect of Condition for heart rate during the TT.


*
*
Pain Affect (0-10)
10
8
6
4
2
0
Pleasant
Neutral
Painful


a.
Heart Rate (b. min-1)
180
160
140
120
0
0 2 4 6 8 10
Time (min)
Pleasant
Neutral
Painful
b.
Blood Lactate (mmol)
12
10
8
6
4
2
0
Rest 5 10
Pleasant
Neutral
Painful
c.
RPE (6-20)
20
18
16
14
12
10
8
6
0 2 4 6 8 10
Time (min)
Pleasant
Neutral
Painful
d.
Pain (0-10)
8
6
4
2
0
0 2 4 6 8 10
Time (min)
Pleasant
Neutral
Painful
*


a.
*
*
300
250
200
150
100
50
0
Power Output (W)
Pleasant
Neutral
Painful
b.
Pleasant
Neutral
Painful
300
250
200
150
0
Power Output (W)
*
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Distance Completed (km)

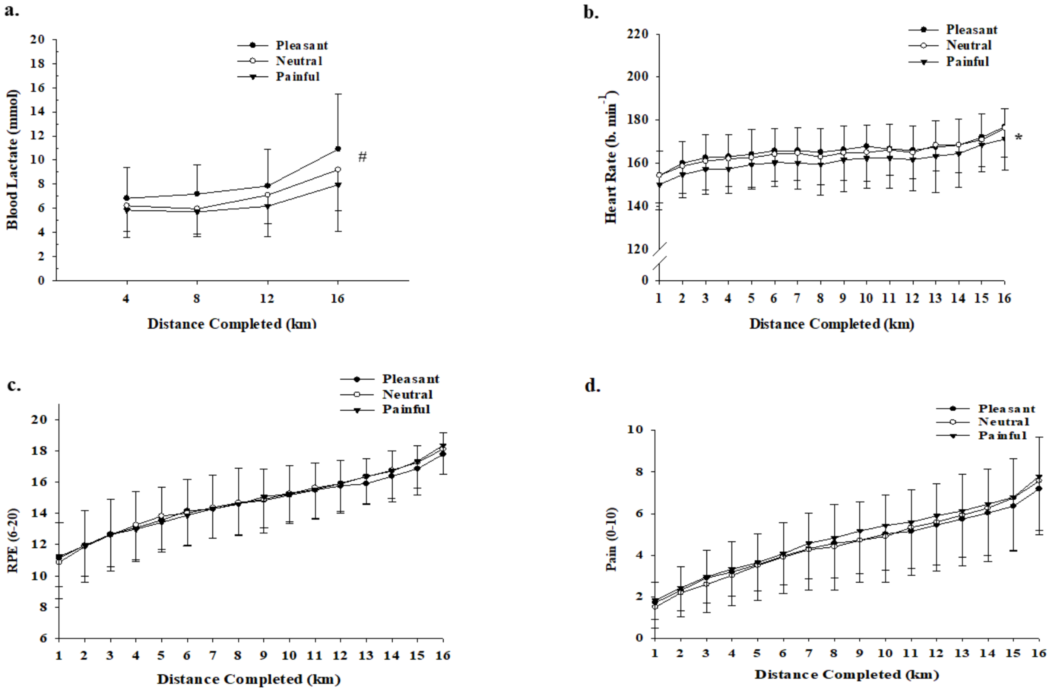

a.
20
18
16
14
12
10
8
6
4
2
0
Blood Lactate (mmol)
Pleasant
Neutral
Painful
#
4
8
12
16
Distance Completed (km)
b.
220
200
180
160
140
120
0
Heart Rate (b. min^{-1})
Pleasant
Neutral
Painful
*
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Distance Completed (km)
c.
20
18
16
14
12
10
8
6
RPE (6-20)
Pleasant
Neutral
Painful
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Distance Completed (km)
d.
10
8
6
4
2
0
Pain (0-10)
Pleasant
Neutral
Painful
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Distance Completed (km)

Table 1. Participant mean values for anthropometric characteristics and cardiovascular and performance parameters.

Variable	Male	Female	Total (F & M)
Age (yrs)	31 ± 7	29 ± 8	31 ± 7
Height (cm)	183 ± 9	166 ± 6	176 ± 12
Body mass (kg)	78.5 ± 15.7	59.5 ± 5.9	71.3 ± 15.8
VO_{2max} (mL/kg/min)	56.7 ± 8.9	49.5 ± 10.8	54.0 ± 10.1
Anaerobic Threshold (W)	164.4 ± 53.1	116.5 ± 30.9	146 ± 51
Peak Power Output (W)	336.1 ± 56.5	214.6± 51.2	290 ± 81
Ramp end pain	7.9 ± 1.7	5.3 ± 2.6	6.9 ± 2.4
Ramp end RPE	18.0 ± 1.5	17.0 ± 2.6	17.6 ± 2.0
Ramp HR_{max} (beat. min^{-1})	181 ± 12	173 ± 18	180 ± 15

RPE, rating of perceived exertion; Ramp, incremental ramp test; HR, heart rate; W, watts.

Table 2. Means and standard deviations for HR, pain, perceived exertion and B[La] during the FP task.

Variable	Pleasant	Neutral	Painful
HR (bpm)	151.209 ± 10.981	152.324 ± 11.584	153.295 ± 12.103
EIP	2.410 ± 1.657	2.510 ± 1.589	2.843 ± 1.642
RPE	12.367 ± 2.538	12.286 ± 2.396	12.838 ± 2.282
B[La] (mmol/L)	7.487 ± 2.772	7.019 ± 2.409	7.851 ± 2.900

HR, heart rate; bpm, beats per minutes; EIP, exercise induced pain; RPE, rating of perceived exertion; B[La], blood lactate; mmol/L, millimoles per litre.

Table 3. Means and standard deviations for HR, pain, perceived exertion and B[La] during the TT task.

Variable	Pleasant	Neutral	Painful
HR (bpm)	165.041 ± 9.391	164.094 ± 11.919	160.545 ± 12.419
EIP	4.408 ± 1.789	4.628 ± 1.698	4.515 ± 1.731
RPE	14.610 ± 1.721	14.732 ± 1.721	14.728 ± 1.655
B[La] (mmol/L)	7.801 ± 2.923	7.316 ± 1.999	6.336 ± 2.311

HR, heart rate; bpm, beats per minutes; EIP, exercise induced pain; RPE, rating of perceived exertion; B[La], blood lactate; mmol/L, millimoles per litre.