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Cortical haemodynamic and physiological correlates of exercise cognition in trained and untrained cyclists over an Incremental self-paced performance test, while thinking aloud

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Running head: Cortical and physiological Indicators of exercise meta-cognition.

A pilot study investigating cortical haemodynamic and physiological correlates of exercise cognition in trained and untrained cyclists over an Incremental Self-Paced Performance Test, while Thinking Aloud.

Abstract

Objectives: Few studies have directly investigated changes in cortical haemodynamics during a self-paced interval endurance activity, while collecting conscious cognition and physiological performance data. This pilot study used functional Near Infrared Spectroscopy (fNIRS), while capturing conscious cognition using Think Aloud (TA) during an incremental paced cycling exercise. **Methods:** A mixed design was implemented with cycling expertise (untrained vs. trained) as the between groups variable and incremental self-paced stage (5 stages of increasing effort) and site (12 optodes across the PFC) as the within groups variables. Dependent measures were the changes in cortical O_2Hb, and physiological indicators (% heart rate max (%HRmax), average power output (APO), peak power output (PPO), rate of perceived exertion (RPE) and blood lactate (Bla)) over time. Participants used TA throughout their second interval trial. **Results:** Trained cyclists had higher APO and maximum power output (MPO) from stages 2 to 5, in addition to a greater increase in PPO over the whole trial. There were significant main effects of stage on %HRmax, Bla and RPE. Differences in cortical haemodynamics were found specifically in areas in the mid left and right PFC. TA data demonstrated that untrained participants verbalised more irrelevant information and feelings of pain and fatigue, in addition to both groups verbalising significantly more motivation-related thoughts during the final stage. **Conclusion:** This pilot is the first to capture changes in Cox, physiological measures and conscious cognition through the use of TA. We demonstrate the potential role of mid- PFC, and how conscious cognition may change over time. This study has implications for coaches and sport psychologists who may want to understand the cognitions of their athlete during an event and support low level athletes in developing a better understanding of the own cognitions.

Keywords: fNIRS; cycling; think aloud; haemodynamics; effort; cognition

Introduction

Over the last decade, research has attempted to understand the mechanisms underlying effective pacing in athletes (de Koning et al., 2011). Pacing is dependent upon many factors, including an athlete's perception of effort, knowledge of an end-point, prior experience, sensory feedback and the metabolic demands of the exercise. Moreover, there is a complex relationship between the physiological demand of exercise at a given pace and mediation of performance by the brain (St Clair Gibson and Noakes 2004; Noakes et al., 2005; Abbiss and Laursen, 2008). Athletes will utilise information about performance, such as time to completion or remaining distance to set, or

adjust their exercise intensity (Jones et al., 2013). However, few studies have directly investigated changes in haemodynamics during a self-paced interval endurance activity, while collecting conscious cognition and physiological data in situ during exercise.

Self-regulation has been shown to be important in endurance exercise (Wolff et al. 2018) and is heavily reliant on the prefrontal cortex (Heatherton et al. 2011). Theories such as the expected value of control theory (Shenhav, et al., 2013), the cost model of subjective effort and task performance (Kurzban et al., (2013), and the idea of the labour/leisure trade off (Kool & Botvinick, 2014) consider how the brain is constantly interpreting its social world. More specifically, these accounts all conceptualize the allocation of self-regulatory control as a reward-based choice, where a person weighs the costs of control against the expected rewards of applying control. In the context of endurance performance, this may be a cyclist thinking "should I push to increase effort or should I give up?". If a performer is required to self-regulate resources to-be-expended on physical effort, a corresponding increase in activation can be seen in cortical areas underlying cognitive control in areas of the PFC (Hallam et al. 2015; Gilbert et al. 2009). It has been found that trained performers are better at self-regulating their efforts during performance (Whitehead et al., 2018), which should be reflected in differences in utilisation of cortical resources for the same task (Ludyga, et al. 2016). Walsh (2014) suggests that research should consider methods and models that can access brain activity in real time under cognitions of stress and activity, which would allow capturing of conscious cognitions and underlying cortical processes during exertion.

Neuroimaging technology appears to be an appropriate method to consider in response to Walsh's (2014) suggestion. fNIRS is an optical neuroimaging tool used to measure the haemodynamic response to brain activation (Leff *et al*., 2011). The measurement is based on the assumption that cortical activity and blood flow are tightly coupled (Holper *et al,* 2009; Villringer & Dirnagl, 1995). fNIRS can be used to measure changes in Cox (Jobsis, 1977), by shining light in the near infrared range (700 – 900nm) directly onto the scalp. Oxygenated (O_2Hb) and deoxygenated

(HHb) haemoglobin have different absorption spectra in the NIR light range (Ferarri & Quaresima, 2012), which can be used to capture localised changes in light attenuation detected at receivers on the scalp, which can thus be attributed to the changes in Cox. In experimental psychology research, fNIRS is a useful neuroscientific tool for elucidating the brain areas associated with distinct cognitive processes (Pinti et al., 2015), changes in mental workload (Hincks et al., 2016) and for assessing group-related pathological changes (Maidan et al., 2015; Montgomery & Roberts, 2017). Within a sporting context, fNIRS has been used to measure active muscle oxygenation changes (Hamaoka et al., 2011; Quaresima et al., 2003). Billaut et al., (2010) used fNIRS to capture cortical oxygenation (Cox) in experienced self-paced runners over a distance of 5km. Over the 5Km, Rate of Perceived Exertion (RPE) increased from 6.6 to 19.1, indicating maximal exertion, while Cox increased from 2.5 and 4.5km. However, during the last 0.5km, where participants had a final sprint and an increase in skeletal muscle recruitment, there was a dip in Cox. Moreover, a drop in cortical oxygenation has previously been associated with exhaustion during whole body exercise at high intensities (Rupp & Perry, 2008; Seifert et al. 2009). A systematic review by Rooks et al. (2010) looked at the effects of incremental exercise on cortical oxygenation measured by NIRS. This review identified that among these studies, prefrontal oxygenation measures with NIRS in healthy people showed a quadratic response to incremental exercise. More specifically, there was a rise in O_2Hb between moderate and hard intensities, with this falling at hard intensities. Furthermore, within their systematic review Rooks et al. (2010) reported that in participants who were aerobically trained attained higher levels of cortical O_2Hb, HHb and total Hb, than untrained during very high intensities. Whereas, in an untrained population there was a marked drop in oxygen levels and a small increase in HHb at very hard intensities, accompanied by declines in tHb, implying reduced blood flow. Given that a certain level of PFC activation is required for effortful cognition and self-regulation, a drop in PFC activity could result in task failure as seen in animal models (Hosking et al. 2016). More recently, Wingfield, Marino and Skein (2019) monitored changes in Cox while manipulating the end-point knowledge of participants performing a cycling trial. Manipulation (or deception) of the end-point caused an

increase in Cox and RPE during a 36-km trial, in addition to a reduction in heart rate (HR) and power output (PO). The authors suggest that changes in Cox in the prefrontal cortex (PFC) influence the regulation of exercise performance when deceived of the duration end-point, by increasing perception of effort to reduce premature onset of physiological strain. This is further supported by Wolff et al. (2018) who found that fNIRS showed activity in the lPFC during endurance performance increased with increasing self-regulation requirements.

While previous research has attempted to assess the role that PFC-moderated cognitive processes and how they may play in exercise regulation, most approaches for collecting this type of conscious cognitive data have been retrospective (e.g. Brick et al., 2016). However, more recently researchers have attempted to capture perceptual cognitive strategies using 'in-event' methods such as Think Aloud Protocol (TA) (Whitehead et al., 2017; Whitehead et al., 2018; Massey et al., 2020). The advantage using of TA is that is allows for the capture of cognitive processes that underpin approaches to performance, in real time. TA requires individuals to verbalise continuously their thoughts over the duration of a task (Ericsson & Simon, 1980). More recently there has been an increase in the number of researchers adopting the use of TA to capture in-event cognitions within endurance sports such as running (Samson, Simpson, Kamphoff, & Langlier, 2015) and cycling (Whitehead et al., 2018; Massey et al., 2020). Furthermore, recent evidence has demonstrated that cyclists report that TA has little effect on their performance in both lab and field data collection protocols, with many expressing how the process came naturally to them (Whitehead et al., 2018).

TA has been used to capture cognition, using self-paced sports such as golf (Nichols & Polman, 2008; Whitehead et al., 2015; 2016) and snooker (Welsh et al., 2018). Research that has used TA in sport has found consistent differences in meta-cognitive expertise. In tennis and golf, more skilled performers engaged in higher levels of planning, whereas lower skilled performers' cognitions were more technical (Whitehead et al., 2015; McPherson & Kernodle, 2007). Within cycling, Whitehead et al. (2018) investigated the cognitive differences associated with pacing

strategies between trained and untrained (inexperienced) participants. Untrained cyclists verbalised significantly more thoughts relating to the time elapsed, feelings of pain and discomfort and irrelevant information whereas trained cyclists verbalised more task-relevant thoughts such as those relating to power output and cadence. This suggests that trained cyclists use active self-regulatory strategies during their performance and maintain a task-relevant focus, whereas inexperienced individuals attempt to use distractive strategies to overcome the perceptions of pain and fatigue associated with exertive exercise. It has been suggested that these types of perceptions are also necessary for trained athletes to monitor, and in some instances may even be considered essential in the accomplishment of goals (Bale, 2006; Simpson, Post, Young, & Jensen, 2014), but those less experienced may only interpret them as negative cues. Theoretically, such findings align with the conscious awareness brain regulation model of pacing (Edwards & Polman, 2013), where exercise is regulated using the athlete's prior experience, knowledge of endpoint and afferent feedback in which pacing is seen as a decision-making process. It is noteworthy that the information-reduction hypothesis postulates that experts can optimise the amount of information processed by allocating their attentional resources to the task relevant stimuli and ignore irrelevant stimuli.

Active monitoring of task-relevant information in relation to the demands of the current task is a key feature of memory updating, a complex higher level "executive function", which is synonymous with the concept of working memory as a whole (Miyake et al., 2000). During exercise, increased Cox has been observed during an active monitoring task in the PFC, and this was correlated with peak power values, and more pronounced in high performers (Bediz et al., 2016). Further, as already mentioned Rooks et al. (2010) reported how those who are more aerobically trained attained higher levels of Cox than untrained during very high intensities. Thus, it seems reasonable to expect that as expertise increases, athletes are able to actively monitor their performance relative to goals more efficiently, and adjust effort accordingly, up to maximal exertion, where Cox may decline as skeletal muscles require extra resources as seen in Billaut et al. (2010). Indeed, utilisation of a particular area of the brain e.g. the PFC via a complex cognitive process is

usually coupled with a localised increase in the need for oxygen. Such neurovascular coupling in response to increased cognitive demand can be measured at the cortical level via changes in oxygenated (O_2Hb) and deoxygenated (HHb) haemoglobin using fNIRS (Izzetoglu et al., 2004).

However, it has not, to the authors' knowledge, been used in conjunction with TA as a corroborative indicator of mental effort during time trials of increasing physiological demand.

In summary, while TA is a useful research methodology, it is not without some limitation. For example, TA requires a participant to verbalise thoughts in the current moment and is reliant on information being processed in working memory. Unconscious and automated processes are, as such, difficult to access, as is how a participant acquires this information. Therefore, it is important to consider how other factors such as physiological and cortical haemodynamic elements contribute to pacing and performance. This research aims to explore the cortical correlates of conscious cognitions (using TA) of two levels of athletic performers (trained and untrained cyclists) to further our understanding of how exercise-related brain activity differs as a function of expertise.

Method

Design

A mixed design was implemented with cycling expertise (untrained vs. trained) as the between groups independent variable and Stage (5 levels) as the within groups independent variable. Dependent variables were the oxygenation change scores at 12 locations in the PFC, and physiological indicators (%HRmax, Bla, RPE, APO, PPO).

Participants

[1]Eight trained male cyclists (40 ± 14 years old, 179.4 ± 6.7cm, 78.1 ± 6.5 kg, training 5 x 75min on average per week on cycling turbo sessions, road bike, swimming and running, with an average 110 ±

[1] Due to a technical failure, only 7 sets of fNIRS data were recorded for the trained cyclists.

40 miles per week cycling training) and seven untrained, physically active males (38 ± 12 years old, 177.9 ± 7.4cm, 82.9 ± 16.5 kg, training 3 x 45min on average a week with a mixture of football, gym, running and rowing, with no distance accumulated cycling) volunteered to take part in the study. Criteria for the trained participants stipulated that they should have a regular training week involving cycling and that they have been training and competing in cycling events over the past 3 years in accordance with recent guidelines (De Pauw et al., 2013). Untrained participants were healthy and physically active but had no prior experience in competitive cycling. All participants provided written informed consent and ethical approval was granted by the institutional research ethics committee before the study was conducted.

Materials

All participants performed the cycling trial on a Watt bike (Watt Bike Trainer, Nottingham). There were two trials completed by each participant. The first trial acted as a familiarisation trial where participants were instructed not to TA, the reason for this was to allow all participants to be familiarised with the testing procedure and self-paced efforts as exercise performance is reproducible in experienced athletes; less trained participants exhibit greater variability in performance and pacing (Hibbert et al., 2017). The second visit to the lab, which was at least 48 hours and no more than 20 days after (average 9 days between) included each participant engaging in TA during the same exercise demand.

Blood lactate measurements were taken from the index finder of each participant using a small lancet to pierce the skin and Lactate 2 Pro Analyser to collect the sample. These were taken at baseline prior to the bike warm up, post warm up and at the end of each 3-minute stage over the test. A chest heart rate strap (T31 Polar) was worn and readings taken at pre, post warm up and at the end of each 3-minute stage. The participant's rate of perceived exertion (RPE) according to the 6-20 scale proposed by Borg (1970), was also taken post warm up, after each stage and they were asked for an overall session RPE at the end (Haddad et al., 2017).

fNIRS: An Oxymon III (Artinis Medical Systems, Netherlands) was used to collect data and the incorporated Oxysoft programme was used for data collection, visualisation and pre-processing. The OxyMon takes topographical readings of up to 4 cm penetration depth, with a sampling rate of 50Hz. Changes in O_2Hb and HHb were assessed across the prefrontal cortex using a 12 channel prefrontal montage. Transmitters (light source) and receivers (light detectors) were fitted in to a neoprene padded head cap (Artinis Medical Systems, Netherlands) which secured on to participants' heads using a Velcro chinstrap. Source-Detector Separation (SDS) was 4.5cm. The sensitivity of the montage was tested using AtlasViewerGUI for Homer2, as per the method in Aasted et al. (2015) (See Figure 1 for montage sensitivity and optode placement). To reduce ambient light interference and further secure the fibre optic cables, an additional black neoprene headband was secured over the head cap, and an IV hook used to prevent the cables from pulling the head cap. Differential Pathway Factors were calculated based on individual participants' age (ranging from 18-57 years), using the integrated algorithm in Oxysoft, based on the data of Duncan et al. (1996).

<<Insert Figure 1 about here>>

A Dictaphone and a clip microphone were used to capture TA verbalisations through the test on the TA cycling trial only. The clip mic was clipped to the participant's collar or cycling jersey, which was attached to a Dictaphone that was kept in the cycling jersey pocket or attached to an arm strap.

Procedure

Although we recognise the importance of a priori power analysis to determine sample size (Schweizer and Furley, 2016), it is important to acknowledge the embryotic nature of this research. Given that this study is acting as a 'pilot' as such a study has never been conducted before and the required inputs for a prior power analysis (e.g. alpha, power effect size) are unknown, therefore a priori power analysis was not overly instructive for this study.

All participants' resting blood pressure and heart rate (Dinamap V100, GE Healthcare) were collected after a 5 minute seated period. Height (cm), body mass (kg) and training history were recorded.

Participants were instructed to avoid any intake of caffeine or alcohol and strenuous exercise in the 24 hours preceding a test session and to arrive at the laboratory in a rested and fully hydrated state. All tests within subjects were performed at the similar time of day in a controlled environmental laboratory condition (19–22 °C), to minimize the effects of diurnal biological variation on the results. After giving consent, age, height and weight were collected. Each test was performed on an electromagnetically-braked cycle ergometer (Wattbike, Training Model, Nottingham) that was calibrated in accordance with manufacturer's guidelines and a Wattbike performance monitor which collected the power, speed and cadence data. Before using the Wattbike participants adjusted the seat height and distance from the handle bars to suit their preference or if they did not know the Wattbike User Guide set up was used. Once comfortable on the bike, the fNIRS head cap was fitted to participants' heads and transmitter/receiver placement was adjusted if necessary, until stable signals were recorded. Participants were then fitted with the chest-strap HR monitor, and introduced to using the Rate of Perceived Exertion scale. A 2-minute baseline of inactivity was recorded for calculating the relative changes in O_2Hb and HHb. There was a warm up guide provided which consisted of five minutes of steady state cycling followed by 2 x 1minute bouts of cycling at the self-regulated pace for stage 1 and then for the self-regulated pace at stage 2. There was then a three minute break until the test started.

The incremental cycling performance test consisted of 5 stages of 3-minutes of continuous cycling and 1-minute active rest in-between each stage to allow for participants to start steady, progress through aerobic and anaerobic threshold zones and finish on a maximal effort to be sustained for a 3 minute period (Faude et al., 2009). Participants were instructed to use the Borg Scale (Borg, 1982) to self-pace five stages of cycling and no verbal encouragement was provided. They were asked to keep the set self-pace consistent for the 3 minutes. At the end of each stage of performance, variables of

average and maximum power output produced were recorded as well as physiological variables of Bla, heart rate and RPE. All trials were performed with the familiarisation trial first followed by the TA trial. The intensity corresponding to the maximal equilibrium between production and removal of blood lactate has been related to aerobic performance during recent decades, therefore using maximal lactate steady state intensity to look at submaximal aerobic capacity is considered the gold standard. The results of the blood lactate finger prick on the conclusion of each stage predicted the participants' anaerobic capacity, which gives an indication of fitness (Heck et al., 1985; Beneke, 2003; Billat et al., 2003; Faude et al., 2009). With the majority of the literature indicating the determination of anaerobic threshold and validity, defined as the power output at [La] of 3.5 $mmol \cdot L^{-1}$, as an indirect index of MLSS (Denadai et al., 2004; Denadai et al., 2005; Figueira et al., 2008; Heck et al., 1985).

For the TA trial, detailed instructions were provided to participants to explain the procedures involved with using the TA protocol. Participants were instructed to engage with a series of TA training exercises adapted from Ericsson and Simon (1993). The TA training exercises involved using Ericsson and Simon (1993) adapted directions for giving TA verbal reports, which included providing verbal reports during the warm-up task and completing non-cycling problems; (1) an alphabet exercise, (2) counting the number of dots on a page, and (3) verbal recall. Participants were instructed to use Level 2 TA and were asked to *"please Think Aloud by trying to say out loud anything that comes into your head throughout the trial. You do not need to try and explain your thoughts and you should speak as often as you feel comfortable in doing so".* Based on recommendations from Birch and Whitehead (2019) participants were also ask to TA during a task specific exercise, which included thinking aloud in the laboratory-environment and task, participants were also asked to TA during the warm-up. During the rest period prior to commencing the trial, participants were asked to confirm that they were fully comfortable with the task of thinking aloud and instructions were again reiterated.

After completion of the final stage 5 trial, participants completed a cool down of 3 minutes steady cycling. The fNIRS head-cap was removed and participants were asked to step off the Watt bike.

Data analysis

Think Aloud

The TA data were transcribed verbatim and time-stamped so that verbalisations could be separated by interval stages. Data were analysed both inductive and deductive content analyses. Where a deductive approach was taken, the metacognitive framework previously used by Whitehead et al. (2018) and originally adopted from Brick, MacIntrye, and Campbell (2014) was used. Using this framework, verbalisations were first coded into broader primary themes (i.e. Internal Sensory Monitoring, Active Self-Regulation, Outward Monitoring and Distraction) and then further coded into more descriptive secondary themes (see Table 1 for description of all themes). Throughout this coding process, the researcher allowed for further inductive themes to be generated. However, during this process rather than these being generated, some were removed from the original coding framework, due to the different nature of the activity. For example, distance was not a value that was presented to participants during the interval stages, therefore it was not something that was verbalised by the participants. In keeping with previous research that has adopted the use of TA to capture athlete cognitions (e.g. Arsal, Eccles & Ericsson, 2016; Whitehead et al., 2017; Whitehead et al., 2018; Swettenham, Eubank, Won, & Whitehead, 2018), a post-positivist epistemology informed this study. Therefore, as recommended by MacPhail et al., (2016), inter-rater reliability was assessed, where one other author analysed a 10% sample of the TA data using the coding framework (Table 1). Following this, the two authors compared codes and an inter-rater reliability of 91% was found. A third author was involved in the discussion of the remaining 9% of the un matched themes, to act as a 'moderator' and once agreements were made, the number of themes were also grouped by interval stage, for both the primary and secondary themes. To explore between-group differences in the number of verbalisations for primary and secondary themes, a series of Mann-Whitney U

Tests were conducted. To explore changes in the number of verbalisations over interval stages, Friedman's repeated-measures tests were used, followed by Wilcoxon Signed Ranks tests as post hoc analyses where significant differences were found.

<Insert Table 1 about here>

Physiological data

All the physiological and performance data was normally distributed. A paired t-test was used to compare the demographic baseline and warm up data between the two groups (trained vs. untrained. Performance and physiological data was then analysed using a series of mixed ANOVAS with group as the between groups variable (2 levels, trained/untrained) and stage (5 levels) as the within groups variable and changes in physiological variables as the dependent variables.

fNIRS

All channels were visually inspected for any movement artefacts (spikes and troughs due to movement and baseline shifts respectively). Movement artefacts, where a large peak or trough could be visualised in the continuous recording were removed manually from the recording. A band pass filter (0.01Hz low cut off; 0.5Hz high cut off) was applied to raw data, and raw data epochs for each stage were then extracted from the continuous recording using time synchronisation markers, after applying the modified Beer-Lambert law logarithm in Oxysoft, to calculate relative O2Hb and HHb changes (µmol). Correlational Based Signal Improvement (CBSI) (Cui et al. 2010) was then applied to the raw data to reduce signal noise interference (from e.g. motion artefacts) by introducing a correction to average haemodynamic change calculations. As CBSI forces O2Hb and HHb to be inversely correlated, it is only necessary to report one of these parameters of Cox after using this method. CBSI corrected O2Hb averages for each channel were calculated, and changes were computed relative to baseline by subtracting the CBSI average for each channel in the baseline period from each channel in each stage. fNIRS data was then analysed using a series of mixed ANOVAS with group as the between groups variable (2 levels, trained/untrained), stage (5 levels) as

the within groups variable and changes in O2Hb at each site measured (optodes 1-12) as the dependent variables.

Results

Trained cyclists (60 ± 10 bpm) had a significantly lower resting heart rate than untrained cyclists (67 ± 4 bpm) (p=.04) . Resting blood pressure (trained 84 ± 18/128 ± 16; untrained 81 ± 14/130 ± 13) and blood lactate measurements (trained 1.4 0.4 Mmol; untrained 1.6 0.3 Mmol) were similar between the groups (p=.04).

Performance Data

After a controlled warm up period participants were asked to self-pace the 5 stages of 3 minutes using the Borg scale of 6-20. As Mauchly's Test of Sphericity was significant, Greenhouse-Geisser adjusted statistics are reported. For %HRMax, there was a significant main effect of stage $F(1.93, 27.03) = 109.60$, $p = 0.00$ $\eta p^2 = 0.89$, see Figure 2. Bonferroni pairwise comparisons revealed HR% of maximum is similar between warm up and stage 1 and 2 (p = .50 & .44 respectively) and differs significantly between stage 1 and every other stage (p = .001 in all cases). The stage*group interaction was non-significant $F(1.93, 27.03) = 0.333$, $p = 0.71$, $\eta p^2 = 0.02$ as was the main effect of group $F(1,14) = 0.03$, $p = 0.87$, $\eta p^2 = 0.00$, indicating that level of expertise was not an important factor in %HR max increases.

For Bla, there was a significant main effect of stage $F(1.76, 24.70) = 82.86$, $p = 0.00$ $\eta p^2 = 0.86$, with significant pairwise comparisons between stages 1 and 2, 2 and 3, 3 and 4, 4 and 5 individually, with the same blood lactate reading post warm up to stage one, p = 1.00 and to stage two p = 0.41 in both groups. The stage*group interaction $F(1.76, 24.70) = 0.85$, $p = 0.43$, $\eta p^2 = 0.06$ was non-significant, as was the main effect of group $F(1,14) = 0.03$, $p = 0.87$, $\eta p^2 = 0.00$.

<Insert Figure 2 about here>

APO was collected at each stage in the trained group spanned from 123-187 Watts, whilst the untrained group ranged from 89-145 Watts. The main effect of stage ($F(1.78,23.14) = 51.37$, $p = 0.00$, $\eta p^2 = 0.79$) was significant. The Bonferroni pairwise comparisons revealed that although each stage showed a higher APO, there was no significant increase in APO from the warm up stage to the 1st ($p = 0.56$) and 2nd stage ($p = 0.12$); from stage 3-5, there were significant increases in APO for each subsequent trial, $p = .05$ in all cases. Trained cyclists had higher APO at each stage compared to the untrained, and there was a trend to significance for the main effect of group, $F(1,13) = 3.70$, $p = 0.08$ $\eta p^2 = 0.22$. The stage*group interaction was non-significant, $F(1.78, 23.14) = 0.41$, $p = 0.64$, $\eta p^2 = 0.03$.

PPO at each stage is displayed in Figure 3.0, and shows that there is a significant difference between the PPO produced by the trained compared to the untrained group at each stage, group $F(1,13) = 5.94$, $p = 0.03$ $\eta p^2 = 0.31$. However, the stage*group interaction was non-significant $F(2.07, 26.94) = 2.10$, $p = 0.14$ $\eta p^2 = 0.14$. Overall the stages showed no significant difference in PPO between warm up and stage 1 ($p = 0.26$) or stage 2 ($p = 1.00$). Pairwise comparisons between each stage from 1 to 2, 2 to 3, 3 to 4 and 4 to 5 revealed significant increases in effort at each stage ($p = .0001$ in all cases), and the main effect of stage was significant $F(2.08, 26.94) = 77.61$, $p = 0.00$ $\eta p^2 = 0.86$.

<Insert Figure 3 about here>

Participant's RPE over the 5 stages increased significantly in both groups, evidenced by the significant main effect of stage $F(2.74, 38.77) = 216.3$, $p = 0.00$, $\eta p^2 = 0.94$, see Table 2.0. Pairwise comparisons revealed that all stages differed from each other above stage 1 ($p = .0001$). There was a significant interaction between stage and group $F(2.74, 38.37) = 3.03$, $p = 0.045$, $\eta p^2 = 0.18$, though the main effect of group was non-significant $F(1,14) = 0.08$, $p = 0.78$ $\eta p^2 = 0.01$.

<Insert Table 2 about here>

The Bla results suggest that anaerobic threshold levels were achieved between stage 2 (2.4 ± 1.0 mmol·L^{-1}) and stage 3 (4.7 ± 2.1 mmol·L^{-1}) for trained cyclists, with the untrained group reaching their submaximal anaerobic capacity sooner at stage 1 (3.6 ± 1.8 mmol·L^{-1}). These results suggest that the trained cyclists had greater aerobic capacities than their untrained counterparts, and a larger range of 'perceived' gears.

Changes in cortical oxygenation

For optodes 1-3, 5-7 and 11 & 12, the effects of stage, the stage*group interaction and the main effects of group were all non-significant (p>.05 in all cases). For brevity, the results for these optodes are not discussed further. Mean changes in cortical haemodynamics for optodes 4, 8, 9 and 10 are displayed in Figure 4, and mean differences and Bonferroni pairwise comparisons between the stages are displayed in Table 3. For oxygenated Hb change, in optode 4 (Superior Medial Left PFC), there was a significant main effect of stage[2] $F(1.57, 20.40) = 5.75$, $p=.015$, $\eta p2 = 0.31$, indicating a decrease in cortical oxygenation over the 5 trials in this area. Bonferroni pairwise comparisons revealed that stage 4 differed significantly from stages 1 and 2. The stage*group interaction was non-significant $F(1.57, 20.40) = 0.83$. $p=0.43$, as was the main effect of group $F(1,13) = 3.19$, $p = .09$. For optode 8 (Superior Right PFC) there was a main effect of stage, $F(1.66, 21.52) = 16.87$, $p<.0001$, $\eta p2 = 0.57$ and inspection of Figure 4 shows that there was a decrease in oxygenation change over the 5 stages. Bonferroni pairwise comparisons revealed that stages 5 and 4 differed significantly from all stages, but not from each other, while stage 3 and 2 differed from each other. The stage*group interaction was non-significant $F(1.66, 21.52) = .58$, $p = 0.68$, as was the main effect of group $F(1,13) = 1.85$, $p = 0.20$. For optode 9 (Superior Medial Right PFC), there was a significant main effect of stage $F(2.14, 27.85) = 30.18$, $p=..0001$, $\eta p2 = 0.70$, indicating an increase in cortical oxygenation over the 5 trials in this area. Bonferroni pairwise comparisons revealed that stages 4 and 5 differed significantly from all other stages. Stage 3 and 1 also differed from each other. The

[2] As Mauchly's test was significant, adjusted df and Grenhouse-Geisser statistics are reported.

stage*group interaction was non-significant F(2.14, 27.85) = 0.59, p=.57, as was the main effect of group F(1,13) = 0.04, p = .85. For optode 10 (Left Anterior cingulate), there was a significant main effect of stage F(1.85, 24.09) = 8.96, p=.002, ηp2 = 0.41, indicating a decrease in cortical oxygenation over the 5 trials in this area. Bonferroni pairwise comparisons revealed that stage 5 differed significantly from stage 1 and differences with stage 2 approached significance. The stage*group interaction was non-significant F(1.85, 24.09) = 1.54. p=0.24, as was the main effect of group F(1,13) = 0.06, p = .81.

<Insert Table 3 & Figure 4 About Here>

Think Aloud findings

There was no significant difference in the total number of verbalisations between trained (Mean Rank = 6.88) and untrained participants (Mean Rank = 9.29; U = 19.00, p = .31). The most common overall secondary theme verbalised was Active Self-Regulation (M = 40.46, SD = 24.00), followed by Internal Sensory Monitoring (M = 18.20, SD = 10.53), Outward Monitoring (M = 14.73, SD = 14.24) and Distraction (M = 6.20, SD = 6.25). Between group comparisons of secondary themes for the whole trial identified that the untrained group verbalised significantly more distraction thoughts (irrelevant information) than the trained group (Mean Rank = 10.86 vs 5.50; U = 8.00, p <.01). Furthermore, the untrained group verbalised significantly more distraction thoughts at interval 3 compared to the trained group (Mean Rank = 10.50 vs 5.81; U = 10.50, p > .04).

Within-group differences across the five interval trials were explored and a main effect was found for Distraction (irrelevant information) (x^2 (4) = 9.64, p = .04) for the trained group. Post hoc analyses identified that the trained group verbalised more in interval trial 1 compared to 5 (Z = -2.07, p = .03, δ = .60). Main effects were also found for Outward monitoring (time) for the trained group (x^2 (5) = 23.41, p = .00,). Post hoc analyses identified that the trained group verbalised more outward monitoring (time) verbalisations in interval trial 5 compared to 1 (Z = -2.53, p = 0.00, δ = -1.60), interval trial 3 compared to 1 (Z= - 2.07, p = 0.03, δ = .90, 4 compared to 2 (Z = -1.98, p =0 .04, δ =

422 .56), 5 compared to 2 (Z = -2.40, p = 0.01, δ = .67), 5 compared to 3 (Z = -2.04, p =0 .04, δ = .16). No
423 significant differences were found across distance quartile for the other themes nor for the
424 untrained group.

425 For the primary themes, within-group analyses of cognitions across the five interval trials
426 demonstrated significant main effects for Irrelevant information (x^2 (4) = 9.64, p = 0.04), Motivation
427 (x^2 (4), 21.50, p = 0.00), and Time (x^2 (4) = 23.41, p = 0.00) for the trained group. Post hoc analyses,
428 as presented in Table 4 demonstrated that verbalisations of irrelevant information decreased from
429 trial 1 to 5, whereas verbalisations of motivation and time increased from trial 1 to trial 5. For the
430 untrained group, significant main effects were found for the themes Fatigue (x^2 (4), 12.77, p = 0.01),
431 Pain (x^2 (4), 10.40, p = 0.03), Cadence (x^2(5), 11.38, p =0.04) and Motivation (x^2 (4) = 23.74, p = 0.00).
432 Post hoc analyses showed that verbalisations of both of fatigue, pain and motivation increased from
433 trial 1 to 5, whereas verbalisation of cadence decreased across the trials.

434 <Insert Table 4 about here>

435 **Discussion**

436 This study aimed to explore the difference in cognitions and Cox in trained and untrained cyclists
437 over 5 stages of 3-minute increment interval test on a static bike. The physiological data
438 demonstrated that the trained group performed the stages from 2 through to 5 in a higher average
439 and peak PO even though their physiological data of blood lactate and % of heart rate max was
440 similar at each stage end point. Using TA, there was no significant difference in the total number of
441 verbalisations between groups, however, significant differences in the types of verbalisations
442 between groups and also across interval trials were found, with untrained verbalising more
443 irrelevant thoughts than trained participants. There were significant decreases in Cox in 3 areas of
444 the PFC over the 5 stages, though this did not differ as a function of group. In addition, there was a
445 significant increase in Cox the Right superior medial PFC over the 5 trials, consistent with an increase
446 in oxygen utilisation as the stages progressed.

The onset of blood lactate accumulation occurred sooner in the untrained participants' stages whilst travelling at lower power outputs, highlighting the significant physiological differences between the two groups. The trained cyclists had lower resting heart rates and were physically active on average more minutes per week in general, and in cycling specific training (road bike and turbo) than the untrained participants. The trained cyclists had lower blood lactate levels and RPE after completing the warm up and after stage 1, which could suggest a better 'self-paced' start compared to the untrained who rate the warm up and stage 1 harder to complete. The trained cyclists having prior training knowledge on how the regulate the exercise demands, having more experience of the exercise and afferent sensory feedback during the exercise informing a teleoanticipatory and feedforward response could be accounted for here (De Koning et al., 2011). The fNIRS results were mixed. Contrary to expectations there were actually decreases in O_2Hb over the 5 stages in 3 optodes (right superior medial PFC, Right PFC, left ACC), though an increase was observed in the right superior medial PFC. This did not differ as a function of group (trained vs. untrained). This is partially supportive of previous research, which has shown increases in Cox during exercise (Billaut et al., 2010; Wingfield et al., 2019). Previous research has also shown us that during high exertion, there is a dip in Cox (Rooks et al., 2010) and this is evidenced in, for example, the final 0.5K of a running trial in Billaut et al., (2010). If we consider that lactate threshold values were reached in stage 1 for untrained cyclists (predicted Maximal Lactate Steady State) and between stages 2-3 for trained cyclists, then this could provide tentative evidence for the diversion of O_2Hb away from cognitive resources to skeletal muscle as exertion demands it. Indeed, Inspection of Figure 4 reveals that the slope of the lines for decreasing Cox appears steeper from stages 2-3 onwards for optodes 4 and 8, and this is supported by increases in the mean differences in Cox between each subsequent stage and the significance of these pairwise comparisons. It is also worthy of note that changes in O_2Hb and HHb from baseline reflect different parameters of cortical haemodynamics. For example, it has been postulated that increases in O_2Hb from baseline indicate an increase in blood flow to that site; in line with neurovascular coupling, as the region becomes

more active, glucose and oxygen utilisation increase which requires an increase in their transport to the brain via O2Hb, and a subsequent excess of O_2Hb (Bunce et al., 2006; Fox et al., 1998). Conversely, increases in HHb indicate changes oxygen consumption in a region – as oxygen is withdrawn from O_2Hb and used by cognitive resources, the result is an increase in HHb (Obrig & Villringer, 2003). Research has found that HHb is most closely related to the Blood Oxygen Level Dependent (BOLD) signal from fMRI (Alderliesten et al., 2014). While we did not analyse the CBSI corrected HHb values in the present study, this method results in O_2Hb and HHb being the inverse of one another. Thus, it seems reasonable to expect that if we have significant *decreases* in O_2Hb in the optodes 4, 8, and 10, this would be accompanied by a significant *increase* in HHb in these same areas. This would provide support for increased oxygen utilisation in these areas as the stages progressed. Given the role of the PFC in general in complex working memory (Funahashi, 2017) and the ACC in perception of pain and emotional responses to that pain (Shackman et al. 2011), we surmise that the cognitive and emotional monitoring requirements of the task increase over the 5 trials as difficulty and RPE increase. However, as a note of caution, the lack of a significant increases in O_2Hb in all areas across the trials is at odds with previous research in Cox during physical activity (e.g. Rooks et al. 2010), so further research is needed to corroborate these findings.

The TA trials showed that untrained participants verbalised more irrelevant thoughts compared to trained participants. This supports previous research that has used TA in cycling (Whitehead et al., 2018) where throughout a 10-mile time trial, untrained participants report more irrelevant or distraction thoughts in comparison to trained participants. This could be explained through the *information-reduction hypothesis* (Haider & Frensch, 1999), which suggests that experts can optimise the amount of information processed by selectively allocating their attentional resources to task relevant stimuli and ignoring irrelevant stimuli, whereas novices may focus more on task irrelevant information. Interestingly, this may also link to a second finding, where trained cyclists' verbalisations of 'irrelevant information' significantly decreased as each trial became more difficult (higher RPE). As the trials progress the trained cyclists may focus on task relevant variables

499 such as time and motivation. In line with previous research (Whitehead et al., 2018), both groups
500 increasingly referred to motivation over the stages. Although the conditions differed between
501 Whitehead et al.'s (2018) time trial and the current study, it could be argued that power output and
502 exertion may have been highest for both studies during these final stages (quartile or interval).
503 Therefore, participants may have been using motivational self-talk as a cognitive strategy, which
504 have been evident in improving endurance performance (e.g. Blanchfield, Hardy, de Morree, Staino,
505 & Marcora, 2014; Miller, 2003). Furthermore, as Cox changes as trials increase, more pain and
506 fatigue is referenced for the untrained group and time is verbalised more in the trained group. In
507 both groups motivational verbalisations or self-talk are adopted as trials progress, consistent with
508 increased self-regulation related to the PFC and ACC. During this time, the labor/leisure (Kool &
509 Botvinick, 2014) trade off may be occurring, where both participants are using motivational self-talk
510 to increase and maintain a higher exertion of effort. This trade off, is even more evident in the
511 verbalisations of untrained athletes as they are verbalising unpleasant feelings associated with the
512 exercise, but choosing to input effort to complete the task.

513 Fatigue and pain verbalisations increased throughout the 5 stages of effort for untrained
514 participants (in line with changes in Cox in the left ACC), similar to Whitehead et al. (2018) and
515 Massey et al. (2020). This is reflected within the RPE data, which showed no significant difference in
516 perceived effort from the trained to untrained cyclists although the interaction between the two
517 groups was significantly different, with trained having a wider range of RPE reported. Consequently,
518 at each stage, even though the trained cyclists were travelling further with higher APO and
519 significantly higher PPO, they experienced a similar level of perceived exertion and produced similar
520 levels of Bla and %HRMax to the untrained cyclists at each stage. This adds to recent evidence that
521 recreational endurance athletes consistently report experiences of unpleasant exercise-induced
522 sensations such as pain, fatigue, exertion and discomfort during exercise (McCormick, Meijen, &
523 Marcora, 2016). How athletes appraise their experiences may differ depending on their level of
524 experience and expertise, for example. Rose and Parfitt (2010) proposed that low-active exercisers

525 have a negative interpretation of interoceptive cues, represented by perceptions of fatigue or
526 discomfort, which causes affective responses to suffer. This is seen within the first stage of the test
527 where untrained cyclists rate a higher RPE. In addition, when exercise is prescribed at a high
528 intensity (above threshold), this has been found to elicit negative emotions, especially when the
529 exercise continues to exhaustion (Ekkekakis, Hall, & Petruzzallo, 2004; Ekkekakis, Hall, & Petruzzallo,
530 2008). Again, these negative emotions and feelings reported via TA (pain and fatigue) were evident
531 with the untrained group, specifically during the latter stages. However, with trained athletes such
532 as endurance runners, it has been previously found that these athletes will accept and embrace
533 feelings of pain and discomfort and consider it as essential in the accomplishment of goals, instead
534 describing discomfort as 'positive pain' (Bale, 2006; Simpson, Post, Young, & Jensen, 2014). It has
535 been suggested that trained performers can monitor their bodily sensations more effectively than
536 untrained (Raglin & Wilson, 2008). Therefore, the trained participants' perceptions of pain and
537 discomfort may not have elicited as much attention. Given their prior experience, trained athletes
538 may be able to effectively appraise these sensations based on this previous experience, which allows
539 them to more accurately interpret and inform the active self-regulation of effort which was seen
540 within our trained cyclists group having a wider spread of RPE over the trial suggesting a better
541 pacing strategy was adopted (Brewer & Buman, 2006). Again, linking this with our fNIRs findings, in
542 both groups oxygen utilisation changed in optodes 4, 8, and 10, while oxygen consumption increased
543 in optode 9. Therefore, it is evident that as working memory monitoring requirements increased in
544 difficulty (RPE), trained athletes evidenced a continued monitoring of their 'time' remaining and
545 employed motivational self-talk as a coping strategy, whereas untrained reported feelings of pain
546 and fatigue as a more prominent thought during this time, whilst also employing this same
547 motivational coping strategy. This is consistent with the role of the PFC in self-regulation seen in
548 previous research (Wolf et al. 2018).

549 Although this study provides a novel contribution to the literature. It is important that we
550 acknowledge its limitations. As with all TA research it is not possible to measure what is unconscious

551 due to an inability for individuals to verbalise decisions that are made unconsciously (Whitehead et
552 al., 2018). Therefore, we can only measure what is in the conscious thought process throughout the
553 duration of the task. In addition, although we adopted training guidelines from Birch and Whitehead
554 (2019) and ensured that all participants felt comfortable using TA and we did provide a
555 familiarisation trial, some participants may report a greater number of verbalisations for what they
556 believe is expected or perceive as important to the study (Nicholls and Polman, 2008). A further
557 limitation is that the sample was all male due to the challenges within recruitment of females and
558 the control of the biological attributes such as hormonal concentration at different stages of the
559 menstrual cycle which may influence performance (Bruinvels et al., 2017; Mendiguchia et al., 2011).
560 Gender differences have been found previously during endurance studies, where female runners are
561 more likely to engage in 'personal problem solving' during marathon training (Schomer & Connolly,
562 2002). Therefore, we suggest that future research considers female participants and gender
563 differences, and a control to recruit females in the early follicular phase of their menstrual cycle
564 (Oosthuyse and Bosch, 2010). It is noteworthy that the sample size was small. Although we did
565 collect similar samples to previous research that has used Think Aloud. Whitehead et al. (2018)
566 collected a sample of ten trained and 10 untrained and Massey et al. (2020) collected a sample of six
567 trained and seven untrained. In addition, studies examining Cox collected data from 10 and 11
568 trained athletes (Wingfield et al., 2019; Billaut et al., 2010). Nonetheless, the effect sizes for the
569 mixed ANOVAs were very large (e.g. .70 for the fNIRS analyses; .89 for the physiological variables).
570 While many of the means were in the right direction and we observed a trend to significance, the
571 majority of interactions were non-significant. Taken together this suggests that the study is
572 underpowered and it would be beneficial to repeat the study with a larger sample to investigate the
573 effects of TA on performance and fNIRS indices in more detail.

574 ***Conclusion***

This study is the first of its kind to examine cortical haemodynamic and physiological correlates of exercise cognition in trained and untrained cyclists over an incremental self-paced performance test, whilst using TA. The study has demonstrated differences in Cox between trained and untrained participants and provided some evidence of the role of the PFC in task monitoring during physiological performance where effort is increasing, and performance will become more difficult over time. In addition, through the use of TA, we have been able to capture conscious cognition of participants as they perform, which also demonstrates how depending on the level and experience of the performer (trained or untrained) conscious cognition during the duration of self-paced incremental performance test, participants will verbalise and appraise their current cognitions differently.

From a practical perspective, we able to demonstrate how both untrained and trained performers perceive a task which involves increasing effort throughout the duration. It is evident that untrained performers who lack experience report more negatively associate verbalisation, rate higher levels of effort in the early stage, and are more likely to dissociate from the task through the verbalisation of irrelevant information, therefore, coaches and psychologist may focus of supporting beginner athletes to understand their pain thresholds and their perceptions of pain and fatigue so that they are able to translate these feelings into 'positive pain' (Bale, 2006; Simpson, Post, Young, & Jensen, 2014). In terms of Cox, it appears that under strenuous exercise, oxygen is diverted from the brain to allow the body to perform adequately, though there is evidence for an increase in oxygen turnover and consumption in some areas demonstrating that mental effort is important for monitoring the goals of the trial. Further research could examine the FNIRS response within the working muscles as well as the cortical haemodynamic during an incremental effort to max to display this spread of demand in both experienced and inexperienced task specific participants.

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Table 1: Description of primary and secondary themes from the Think Aloud verbalisations.

Secondary Themes	Primary Themes	Description	Example of raw data quotes
Internal Sensory Monitoring	Breathing	Reference to breathing or respiratory regulation	"My breathing's starting to increase" (Trained, P01) "Just get the breathing up. Gonna need the oxygen" (Untrained, P15)
	Pain	Reference to physical or mental pain	"So much pain" (Trained, P03) "I'm starting to hurt, that's not good" (Untrained, P13)
	Fatigue	Any reference to fatigue and reduction in perceived energy.	"Can feel my legs tiring now" (Trained, P05) "I'm getting those tired feelings" (Untrained, P13)
	Heart Rate	Increasing or decreasing of heart rate, or statement of heart rate value	"Heart seems okay" (Trained, P08) "Heart rate's gone up a bit" (Untrained, P14)
Active Self-Regulation	Cadence	Verbalisations relating to pedal stroke	"80 RPM, keep that cadence" (Trained, P02) "I'm at 50, having a nightmare today" (Untrained, P09)
	Speed	Reference relating specifically to speed	"Keep the speed up" (Trained, P07) "Good speed" (Untrained, P09)
	Power	Reference relating to power output or watts	"Want to aim for between 115 – 120 at this second stage" (Trained, P06) "Watts are good" (Untrained, P13)
	Pace	Reference to purposeful strategy or action-based changes to pace	"Keeping the pace nice and consistent" (Trained, P01) "Pace gone too high, settle down" (Untrained, P11)
	Motivation	Verbalisations relating to self-motivation or positive encouragement	"Come on, push it" (Trained, P04) "Keep it up, that's good" (Untrained, P10)

Outward Monitoring	Time	Reference to time, time elapsed or expected finish time	"Half way", "20 seconds left" (Trained, P01) "30 seconds gone" (Untrained, P11)
Distraction	Irrelevant Information	Verbalisations not relevant to the given task	"I shouldn't have had that sandwich, it's repeating on me now" (Trained, P05) "I wonder how Jess has got on. Give her a ring later" (Untrained, P12).

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Table 2 - Rate of perceived exertion (RPE) over the 5 stages of efforts in both the Trained (n=8) and Untrained (n=7) groups.

Stages	Trained	Untrained
Warm up	8 ± 2	10 ± 1 *
Stage 1	9 ± 1	10 ± 1*
Stage 2	12 ± 1	12 ± 1
Stage 3	15 ± 1	14 ± 1
Stage 4	17 ± 1	16 ± 2
Stage 5	20 ± 1	19 ± 1
Session RPE	15 ± 2	15 ± 2

* indicates there is a significant difference between untrained and trained groups $p<0.05$

Table 3: Mean differences and Bonferroni pairwise comparisons of cortical oxygenation change for optodes with significant main effects, across the 5 stages.

		Optode							
Stage		4		8		9		10	
Stage		M	p	M	p	M	p	M	p
2	1	-.38	1.00	.18	1.00	1.43	.20	-1.24	.98
3	1	-1.44	.92	-1.14	1.00	2.28	.01	-2.1	.45
	2	-.06	.20	-1.33	.04	.85	.30	-.86	1.00
4	1	-3.44	.05	-3.78	.01	4.08	.003	-3.57	.09
	2	-3.06	.03	-3.98	.001	2.65	.001	-2.33	.09
	3	-2.00	.23	-2.65	009	1.79	.21	-1.47	.88
5	1	-.87	.19	-7.30	.007	6.64	.0001	-7.39	.02
	2	-.48	.20	-7.49	.004	5.21	.0001	-6.14	.05
	3	-4.43	.39	-6.16	.008	4.35	.001	-5.28	.09
	4	-2.43	1.00	-3.51	.27	2.56	.01	-3.82	.62

888 Table 4: Within-group comparisons of primary themes verbalised across five interval trials.

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Secondary Theme	Primary Theme	Group	Quartile Difference	Post-Hoc Analysis Wilcoxon Rank (Z)	Cohen's δ	Signf. (*p*)
Active Self-Regulation	Motivation	Trained	Trail 1 – Trial 4 *	-2.02	-1.25	.01
			Trial 1 – Trial 5 *	-2.53	-1.37	.01
			Trial 2 – Trial 5 *	-2.53	-.87	.01
			Trial 3 – Trial 5 *	-2.53	-.78	.01
			Trial 4 – Trial 5 *	-2.04	-.64	.04
		Untrained	Trail 1 – Trial 4 *	-2.03	-1.29	.04
			Trial 1 – Trail 5 *	-2.37	-2.34	.02
			Trial 2 – Trial 4 *	-2.06	-1.07	.03
			Trial 2 – Trial 5 *	-2.37	-2.24	.01
			Trial 3 – Trial 5 *	-2.38	-2.07	.01
			Trial 4 – Trial 5 *	-2.37	-1.57	.02
	Cadence	Untrained	Trial 1 * – Trial 5	-2.05	1.80	.04
			Trial 2 * – Trial 5	-2.04	1.73	.04
Internal Sensory Monitoring	Fatigue	Untrained	Trial 1 – Trial 3 *	-2.04	-1.63	.04
			Trial 1 – Trial 4 *	-2.07	-1.74	.03
			Trial 2 – Trial 3 *	-2.07	-1.81	.03
			Trial 2 – Trial 4 *	-2.12	-1.36	.03
	Pain	Untrained	Trial 1 – Trial 5 *	-2.32	-1.60	.02

			Trial 2 – Trial 5 *	-2.04	-1.75	.04
			Trial 3 – Trial 5 *	-2.05	-1.60	.04
Outward Monitoring	Time	Trained	Trial 1 – Trial 3 *	-2.07	.90	.03
			Trial 1 – Trial 5 *	-2.53	1.04	.00
			Trial 2 – Trial 4 *	-1.98	.56	.04
			Trial 2 – Trial 5 *	-2.40	.67	.01
			Trial 3 – Trial 5 *	-2.04	.16	.04
Distraction	Irrelevant Information	Trained	Trial 1 * – Trial 5	-2.07	.60	.03

***** *denotes significantly higher number of verbalisations*

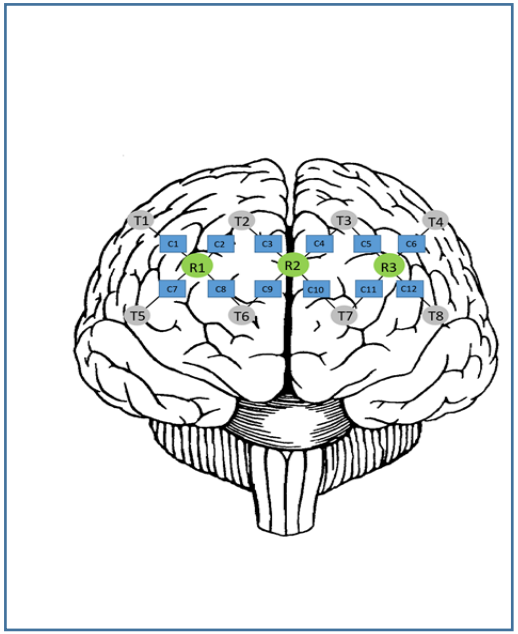


Figure 1a – Oxymon 12-channel prefrontal montage displaying the positioning of transmitters (T) and receivers (R). Each optode (C) equals the path between one transmitter and one receiver, SDS 4.5cm. MNI coordinates for optodes: 1 (42 59 26); 2 (18 50 23); 3 (10 53 24); 4 (-2 46 21); 5 (-12 47 20); 6 (-24 45 16); 7 (39 57 0); 8 (20 52 0); 9 (13 74 1); 10 (-4 57 4); 11 (-20 71 1); 12 (-30 61 1).

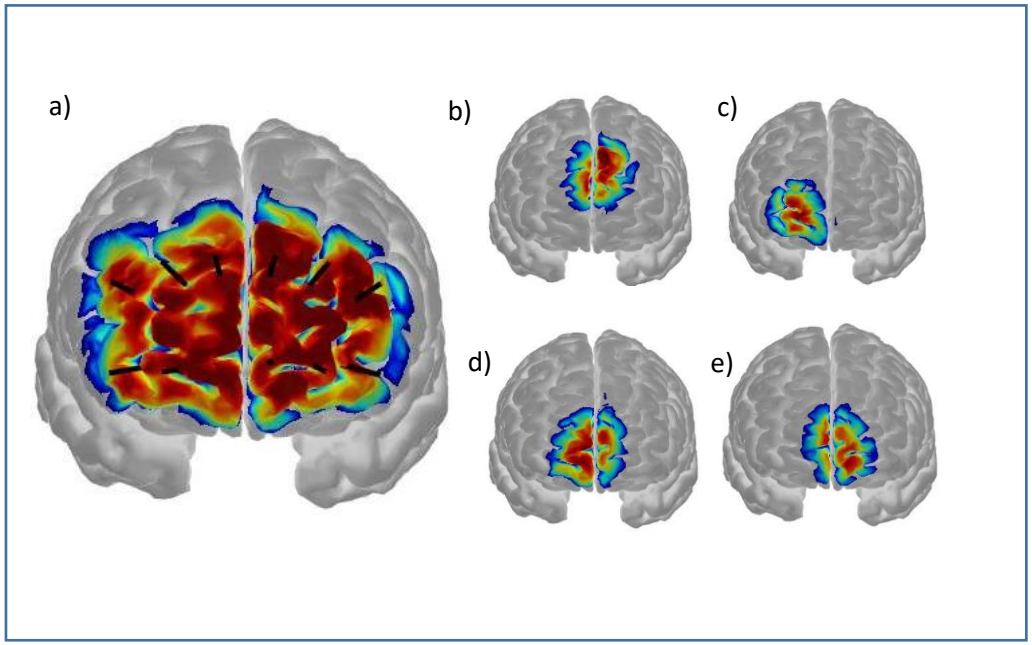
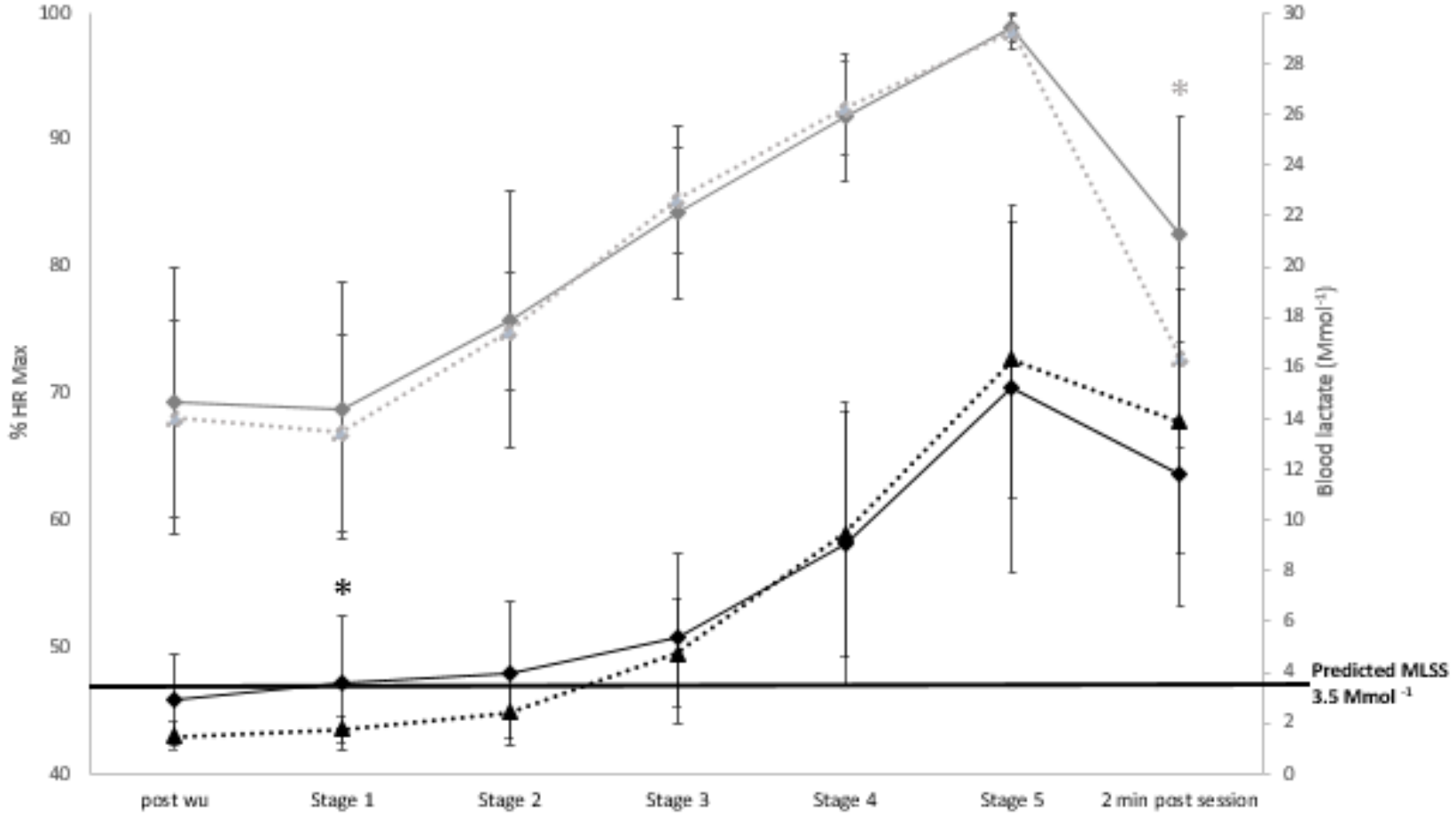


Figure 1b – Sensitivity profile created using AltasViewerGUI for Homer2 as per Aasted et al. (2015) for full montage (a), optode 4 (b), optode 8 (c), optode 9 (d) and optode 10 (e).



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908 Figure 2 – Trained (dashed line) and Untrained (solid line) blood lactate (black) and heart rate % of maximum (grey) data with standard deviation bars, from post warm up
909 through the 5 stages where data was taken immediately after each stage completing. Post session data was taken 2 minutes after the final stage was completed.

910 * represents significant differences between Trained and Untrained blood lactate responses, $p < 0.05$.

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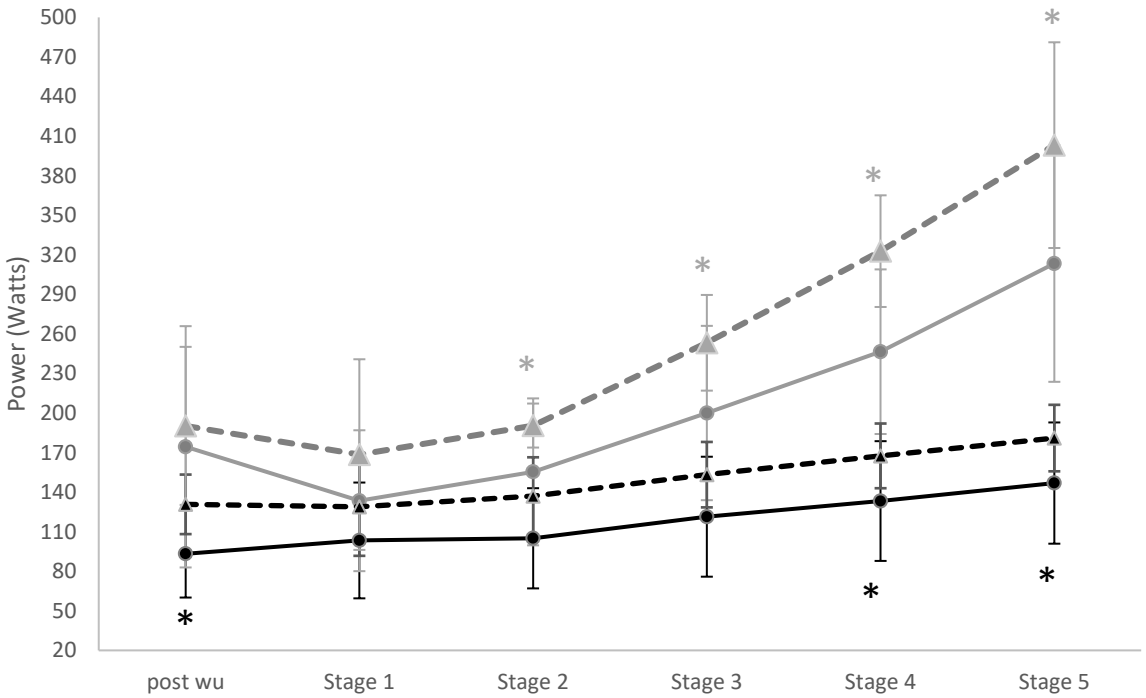

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913 Figure 3 - Trained (dashed line) and Untrained (solid line) average stage power (black) and maximal stage power (grey) data with standard deviation bars, from post warm
914 up through the 5 stages where data was taken immediately after each stage completing as a moving average and the maximal power obtained in the last stage

915 *represents significant differences between Trained and Untrained, $p<0.05$

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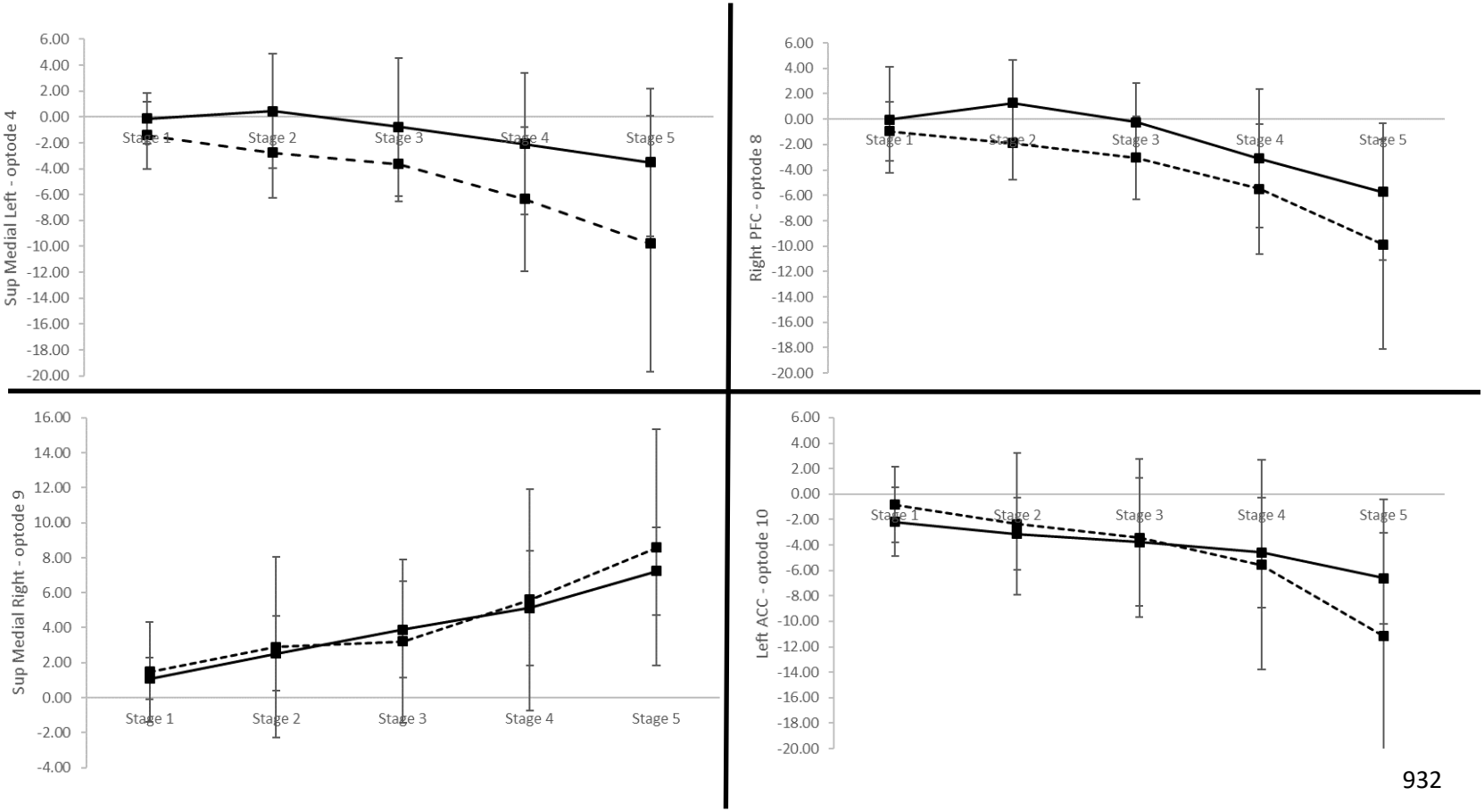

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933 Figure 4: Mean and standard deviations of optodes with significant changes in O_2Hb across the 5 stages in untrained (solid lines) and trained cyclist (dashed
934 lines).

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