THE EFFECTS OF PRIOR POSTACTIVATION POTENTIATION ON 4 KM CYCLING TIME TRIAL PERFORMANCE

by

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ABSTRACT

The aim of this study was to examine the effects of post-activation potentiation (PAP) on performance and physiological measures during endurance cycling. Eleven well trained male endurance cyclists (mean ± SD; 32.7 ± 10.3 yr; 70.7 ± 7.2 kg; VO_{2max} 65.3 ± 5.3 $ml \cdot kg^{-1} \cdot min^{-1}$) performed two 4 km cycling time trials on separate days following 5 minutes recovery after a) a moderate intensity cycling warm-up at 60% of VO_{2peak} for 6.5 minutes (CONTCOND), and b) a PAP-inducing cycling warm-up (PAPCOND) consisting of 5 minutes at 60% of VO_{2peak} then 3 x 10 s at 70% of peak power interspersed with 30 s recovery, in a counterbalanced design. Before the start of the time trial blood lactate was significantly elevated following PAP-inducement compared to the moderate warm-up (4.88 ± 1.36 $mM \cdot L^{-1}$ vs 1.14m ± 0.26 $mM \cdot L^{-1}$). A non-significant possibly small improvement in completion time (1.7 ± 3.5 s, P = 0.17) and a non-significant increase in power (5.1 ± 10.5 W, P = 0.16) were attributed to PAPCOND. Following PAPCOND oxygen uptake (VO_2) was elevated by 1.44 ± 1.65 $ml \cdot kg^{-1} \cdot min^{-1}$ (P = 0.02) and respiratory exchange ratio (RER) was decreased by 0.05 ± 0.02 (P < 0.01) compared to CONTCOND. All differences were greatest in the first 1500 m. A PAP-inducing warm-up leads to small performance improvements in endurance cycling that are associated with elevated blood lactate and increased VO_2. These performance improvements are most evident in the early stages so would be of greatest benefit in short endurance cycle races.

DECLARATION

No portion of the work referred to in this Research Project has been submitted in support of an application for another degree or qualification of this, or any other University or institute of learning.

The project was supervised by a member of academic staff, but is essentially the work of the author.

Signed ……..

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1. INTRODUCTION

Before athletic events most competitors will perform some kind of warm-up activities in the expectation that they will enhance their performance (Bishop, 2003b). Indeed the review by Fradkin, Zazryn and Smoliga, (2010) demonstrates that many studies have found warm-ups have a beneficial effect, although the mechanisms by which they work differ due to the type, intensity and duration of the warm-up. These mechanisms include increasing muscle temperature (Shellock & Prentice, 1985), the speeding up of oxygen uptake (VO_2) kinetics (Burnley, Doust, & Jones, 2005) and improving efficiency by reducing the oxygen cost of performance (Barnes, Hopkins, McGuigan, & Kilding, 2015). Warm-ups also risk negatively affecting performance should they induce fatigue by being too intense (Sargeant & Dolan, 1987), having insufficient recovery before the event (Needham, Morse, & Degens, 2009), or elevating body temperature (Bishop & Maxwell, 2009).

A number of different types and strategies of warm-up exist to elicit the above responses including active warm-up, passive warm-up, and stretching (Bishop, 2003a; Kilduff, Finn, Baker, Cook, & West, 2013). One contemporary technique undergoing greater scrutiny in the search for performance gain is Post-activation potentiation (PAP). PAP is a phenomenon where the performance of a muscle is enhanced by its recent contractile history (Hodgson, Docherty, & Robbins, 2005) resulting in an increased rate of force development (RFD) in its fibres (Jubeau, Gondin, Martin, Van Hoecke, & Maffiuletti, 2010). Whilst the underlying mechanisms behind PAP are still to be fully determined (Robbins,

2005), there are two different mechanisms often suggested as the explanation for the phenomenon; the phosphorylation of myosin regulatory light chains (RLC) (Levine, Kensler, Yang, Stull, & Sweeney) and neural factors enhancing motor unit recruitment (Anthi, Dimitrios, & Christos, 2014). Phosphorylation of myosin RLC results in the actin-myosin interaction becoming more sensitive to calcium ions released from the sarcoplasmic reticulum (Sale, 2002). This is thought to increase the rate of the cross bridging action, effectively increasing the RFD (Hodgson et al., 2005), whereas increased neural excitability leads to a greater number of motor units being recruited consequently increasing in the number of higher order motor units recruited and resulting in an increased RFD (Anthi et al., 2014).

Whether the underlying mechanism behind PAP is phosphorylation of myosin RLC, enhanced neural excitability or a combination of factors, the effect of PAP does not extend to increasing maximal force due to the saturated concentration of calcium found in the presence of high frequency tetanic contractions (Sale 2002). Conversely low frequency tetanic contractions, typical of sustained submaximal contractions have been found to produce an increased RFD (Vandenboom, Grange, & Houston, 1993). PAP has also been shown to be more pronounced in type II muscle fibres (Hamada, Sale, MacDougall, & Tarnopolsky, 2003) due to their higher levels of myosin light chain kinase (Ryder, Lau, Kamm, & Stull, 2007) and their greater activation according to Henneman's size principle (Henneman, Somjen, & Carpenter, 1965). These combined characteristics have led to a number of PAP studies being carried out in submaximal explosive sports such as sprinting, jumping and throwing (Bevan,

Cunningham, Tooley, Owen, Cook, & Kilduff, 2010; Hirayama, 2014; Mitchell & Sale, 2011; Tillin & Bishop, 2009), demonstrating that PAP can enhance performance if the inducement loads and recovery parameters are favorable. Sale (2004) proposed that PAP would be beneficial to general endurance performance where submaximal forces are repeatedly exerted, invoking the low frequency tetanic contractions where calcium sensitivity is a factor in the force production. Although prior activation of a muscle beneficially induces PAP, there is also the coexisting effect of fatigue to be considered, which can produce a net negative effect in performance (Rassier & Macintosh, 2000). The balance of PAP and fatigue was evident in the study by Chiu et al. (2003), who found that the training status of participants influenced the overall response to PAP with *athletes* displaying enhanced performance compared to *recreationally trained* participants. Hamada, Sale, and Macdougall (2000) exploited the trained status of different muscle groups within their participant groups of cyclists (lower body trained) and triathletes (lower and upper body trained), to demonstrate how the training status of individual muscle groups affects their response to PAP. It was suggested that endurance training had enhanced fatigue resistance and the increased number of myosin light chains in the type I muscle fibres within the trained muscle groups.

Whilst it can be argued that all muscle activity induces PAP to some extent (Sale, 2004), therefore many warm-up studies may have unwittingly incurred the benefits of PAP, surprisingly few studies have explicitly examined its effect on endurance performance. However, one recent study by Barnes et al. (2015), did observe increased endurance running performance using trained endurance

runners after a PAP inducing warm-up running strides with a weighted vest. Typically PAP-inducing protocols have used either ballistic exercise with movement at maximum velocity (Maloney, Turner, & Fletcher, 2014) or heavy resistance exercise (HRE), often in repeated bouts of muscle activity lasting 10 s (Vandervoort, Quinlan, & McComas 1983). HRE protocols often use a load based on a high percentage of a participant's one-repetition maximum lift (Seitz, de Villarreal, & Haff, 2013), interspersed with short recovery periods and a longer recovery period before the measurement of the key performance variable (Wilson et al., 2013). Barnes et al. (2015) attempted to make the PAP inducement sport-specific by undertaking 6 x 10 s runs in a weighted vest with 30 s recovery in between. Another feature of the Barnes et al. (2015) study was that it investigated the otherwise unexamined relationship between PAP and VO_2, albeit only measured at submaximal levels. VO_2 is a performance-limiting component of endurance, and as such characterises many endurance performance based studies (Christensen & Bangsbo, 2015; Faisal, Beavers, Robertson, & Hughson, 2009; Jones, Wilkerson, Burnley, & Koppo, 2003) but as yet, owing to the lack of research, no inferences can be drawn as to the positive or negative effects of PAP on VO_2.at perimaximal and supra-maximal intensities.

The effects of PAP have been investigated in sprint cycling (Baker et al., 2008; Smith, Fry, Weiss, Li, & Kinzey, 2001; Tomaras & MacIntosh, 2011) and whilst the results of these studies have been equivocal, they have highlighted the importance of training status and the balance of PAP and fatigue in obtaining improvements in power output. There have also been many studies into the

effects of warm-up routines but not PAP per se (Burnley, Doust, Carter, & Jones, 2001; Hajoglou, et al., 2005; Palmer, Jones, Kennedy, & Cotter, 2009; Wilkerson, Koppo, Barstow, & Jones, 2004), demonstrating how certain warm-up routines can produce power and speed improvements in endurance cycling, particularly in the early stages of performance. The 4 km individual track pursuit race is a cycling endurance event performed at supra-maximal intensity in terms of VO_2, and yet it is estimated to rely on an 85% aerobic contribution (Jeukendrup, Craig, & Hawley, 2000) for its energy supply in male athletes. Sale (2004) advocates that PAP would be effective for endurance events and also suggests that PAP has a self-perpetuating effect due to the on-going contractile history of the muscle. For those reasons it could be argued that a short, intense endurance event such as a 4 km pursuit would be the ideal candidate for the positive effects of PAP. In particular, it seems likely that such a benefit would be evident in the early stages of the event prior to the self-perpetuating component being established, and where a small performance gain could be a race-winning margin.

A performance gain in a race such as the 4 km pursuit is measured in time, however speed and completion time are a function of power output (Jeukendrup et al., 2000), which in turn is derived from the force-angular velocity relationship in pedalling (Sargeant, Hoinville, & Young, 1981). The sustainable power output produced and the maximization of both aerobic and anaerobic energy systems are critical to the 4 km pursuit (Craig et al., 1993). The effects that PAP may have on force, power and the energy systems at supra-maximal intensities are currently unknown. The principal aim of this study was therefore, to compare a

cycle specific warm-up routine inducing PAP with a moderate intensity warm-up cycling at 60% of $VO_{2peak,}$ to determine whether there is a performance benefit for well-trained cyclists over a 4 km time trial. Specifically, it was hypothesised that the PAP warm-up would enhance force, power output and 4 km time compared to the alternative warm-up. In addition, the study examined the effects of these warm-ups on certain physiological measures that relate to overall performance.

2. METHODS

Participants

Eleven healthy males were invited to volunteer to participate in the study (mean ± SD; age 32.7 ± 10.3 years; height 180.9 ± 7.7 cm; mass 70.7 ± 7.2 kg), that had prior approval by the University of Chester's Faculty of Life Sciences ethics committee. The participants were well trained, competitive endurance cyclists, ranging from regional to international level (VO_{2max} 65.3 ± 5.3 $ml \cdot kg^{-1} \cdot min^{-1}$; training volume 8.9 ± 2.7 $hours \cdot week^{-1}$; training experience 9.6 ± 7.5 years). All participants gave written informed consent prior to their participation and completed a health screening questionnaire before each exercise session. Prior to the start of each test a detailed explanation of the test was given to the participant, along with instruction on how to interpret and use the subjective rating scales for effort and pain. Everyone undertook all components of the study, however one participant did not complete the post-activation potentiating component satisfactorily and his data has been excluded from the results.

Experimental Design

In a repeated measures counter balanced design, participants visited the laboratory on three separate occasions over a maximum of 10 days. During the first visit participants undertook a graded incremental cycling test to exhaustion to determine power output intensities relative to VO_{2peak} and a cycling maximum power test, in order to determine individual intensities for use in the experimental trials. After a rest period of approximately one hour, participants then completed a familiarisation of the experimental trial conditions. Between 2

and 7 days later the participants returned for their first experimental trial; 24–96 hours after that they undertook their final and alternate experimental trial. The experimental trials consisted of either the control condition (CONTCOND) and a 4 km time trial, or the PAP inducing condition (PAPCOND) and a 4 km time trial. Participants were asked to refrain from alcohol and caffeine on the day of any sessions, not to have eaten or untaken any strenuous exercise in the preceding 24 hours. The two experimental sessions were conducted at approximately the same time of day under similar air-conditioned environmental conditions within the Department of Sports and Exercise Science laboratory at the University of Chester. The two ergometers used in the sessions were set up based on measurements the participants supplied from their own bicycles, which were then replicated in subsequent sessions. Participants also used their own shoes and preferred pedal type throughout.

The key dependent variables measured during the 4 km trials were time, power output (PO) and force. Other physiological and perceptual markers of performance measured were VO_2, Volume of carbon dioxide expired (VCO_2), blood lactate, heart rate (HR), ratings of perceived exertion on a scale of 6 to 20 (RPE; Borg, 1970) and leg pain on a 1 to 10 scale (Cook, O'Connor, Oliver, & Lee 1998).

Procedures

Baseline tests

A graded incremental cycling test was performed on an electronically braked ergometer (Lode Excalibur Sport, Lode BV, Groningen, Netherlands). Cycling

commenced at 120 W at a self-selected cadence and was increased by 30 W every 3 minutes until volitional exhaustion. Blood lactate was measured in the final 30 s of each stage via a finger-tip blood sample (Lactate Pro II, Arkay, Kyoto, Japan), together with the participant's RPE. Pulmonary gas exchange was measured breath-by-breath using an online gas analysis system (Oxycon Pro, Viasys Healthcare, Hochenberg, Germany), which was calibrated automatically prior to the test with ambient air, humidity readings and gases of known concentrations. VO_2 was averaged over each 30 seconds and VO_{2peak} was determined as the largest of the averaged values recorded. The VO_2 for each stage was defined as the average VO_2 recorded in the final minute. The PO relating to 60% of the VO_{2peak} was interpolated from stages for use in the later experimental trials. Lactate thresholds were noted as the PO at 1 $mM \cdot L^{-1}$ above baseline values. PO at 60% of VO_{2peak} was checked to confirm it was below the lactate threshold for each participant.

Following a rest of approximately 30 minutes, two maximum power cycling tests were performed on a Wattbike Pro cycle ergometer (Wattbike Ltd., Nottingham, UK). Following a brief warm-up the participants performed two 6 s sprints separated by approximately 5 minutes. Peak power (PP) was recorded as the maximum PO reached during the two attempts. A value equating to 70% of PP was then recorded for use in the later experimental trials.

Familiarisation trial

The familiarisation trial conducted after the baseline tests followed the same procedure as the PAPCOND experimental trial (described below). During the

familiarisation trial however, the resistance setting of the Wattbike Pro could be altered by the participant to a preferred setting, which was retained for both subsequent experimental trials.

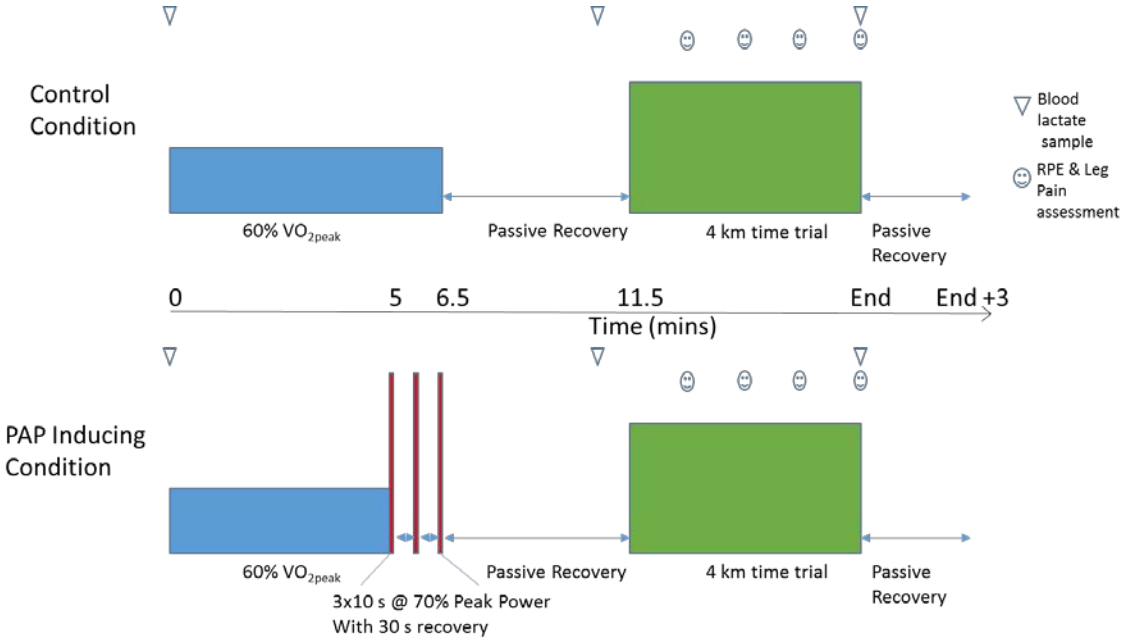

Figure 2. Schematic showing the timeline for both experimental trials.

Experimental trials

During each experimental trial the participant completed either the CONTCOND or PAPCOND on the Lode ergometer followed by a 5 minute passive recovery and a 4 km time trial on the Wattbike Pro. The CONTCOND consisted of a 6.5 minute cycle at the PO calculated to elicit 60% VO_{2peak}. The PAPCOND consisted of a 5 minute cycle at the same power output eliciting 60% VO_{2peak}, immediately followed by 3 bouts of 10 seconds at a power equal to 70% PP, with 30 seconds passive recovery between bouts (see Figure 1). Participants were instructed to aim for a slow cadence of 60 $r \cdot min^{-1}$ for the 10 second bouts and their usual preferred cadence at other times. Following 5 minutes of passive recovery participants were instructed to perform the 4 km time trial as if

it were a race by completing the distance in the shortest possible time, using the drop handlebar position. The resistance setting selected during familiarisation was used throughout the 4 km trials. Participants were also requested to maintain the same pacing strategy for both experimental trials. All instantaneous details of speed, power, time and cadence were withheld from the participants in order to minimise self-pacing cues. Participants were verbally informed of their elapsed distance after each 500 metres completed. Non-specific verbal encouragement was given throughout. Following completion of the trial participants were asked to remain seated passively for a further 3 minutes. Three blood lactate measurements from finger-tip samples were taken at rest; 1 minute prior to the start of, and at completion of the trial. After each km of the 4 km trial the participant was asked to indicate their RPE and leg pain. HR via a chest strap (Polar Electro Oy, Kempele, Finland) and breath-by-breath pulmonary gas exchange were recorded throughout the 4 km trial and 3 minute recovery. The Wattbike Pro calculated distance and recorded time, power, cadence and force dynamics for each pedal revolution throughout the trials. Split times for each 500 metres were computed from the Wattbike Pro data using custom built spreadsheets in Microsoft Excel 2013 (Microsoft Corp., California, US) and interpolation of the elapsed times of pedal strokes. Force, PO, VO_2, VCO_2 and HR were also computed using custom spreadsheets to extract data for each 500m split.

Statistical Analysis

Descriptive Statistics (mean ± SD) were calculated for each dependent variable across each trial. The normality of distributions of the dependent variables were

checked using the Shapiro-Wilkes statistic. Inferential statistics were then used to test the main research hypotheses. Specifically paired sample *t*-tests were used to assess differences in overall completion time, PO and force variables due to the condition type (CONTCOND/PAPCOND). Two-way repeated measures analyses of variance were performed to assess the variability of the mean scores due to condition type (CONTCOND/PAPCOND) and distance (500 m splits). Sphericity was checked with Mauchly's test and accounted for where necessary using the Greenhouse-Geisser adjustment. Paired sample *t*-tests were used post-hoc where appropriate on pair-wise conditions. Statistical significance was set at $P < 0.05$ throughout, with Bonferroni corrections where appropriate. Analysis was performed using SPSS v.21 (IBM Corp., Armonk, NY, US). Effect sizes and magnitude based inferences were calculated using spreadsheets from Hopkins (2006), and interpreted based on the completion times of the top 10 finishers in the November 2012 UCI omnium World Cup 4 km time trial and the suggestions from Batterham and Hopkins (2006).

3. RESULTS

Pre-experimental trials

No significant differences were found in blood lactate concentrations (CONTCOND: 1.21 ± 0.38 mM·L^{-1}; PAPCOND: 1.27 ± 0.46 mM·L^{-1}, *P* = 0.72) and resting VO_2 (CONTCOND: 6.37 ± 0.77 ml·kg^{-1}·min^{-1}; PAPCOND: 5.98 ± 0.94 ml·kg^{-1}·min^{-1}, *P* = 0.37) before the start of the conditioning exercises. Blood lactate concentrations measured 60 s before the start of the 4 km experimental trials were significantly higher (*P* < 0.01) following PAPCOND (4.88 ± 1.36 mM·L^{-1}) compared to CONTCOND (1.14m ± 0.26 mM·L^{-1}).

4 km time trial

Completion times for the 4 km time trial were non-significantly shorter following PAPCOND than following CONTCOND (1.7 ± 3.5 s, *P* = 0.17). Similarly, mean PO (5.1 ± 10.5 W, *P* = 0.16) and mean peak force (5.7 ± 11.0 N, *P* = 0.13) differences both exhibited non-significant improvements following PAPCOND. Individually 7 out of 10 participants completed the 4 km trial faster after PAPCOND than CONTCOND, whilst 3 were slower. Probabilistic inferences suggest a *possibly small* improvement in completion times and *possibly trivial* increases in both PO and mean peak force. Gas analysis during the trials revealed a *likely trivial* and significant increase in VO_2 of 1.44 ± 1.65 ml·kg^{-1}·min^{-1} (*P* = 0.02) due to the PAPCOND, whilst VO_{2peak} increased in 8 out of the 10 participants the magnitude of the non-significant increase of 0.65 ± 1.17 ml·kg^{-1}·min^{-1} (*P* = 0.11) was *trivial*. VCO_2 was lower in PAPCOND than CONTCOND by 1.19 ± 2.51 ml·kg^{-1}·min^{-1} (*P* = 0.17), however when divided by

VO_2 to produce the respiratory exchange ratio (RER) which is indicative of metabolic effects a significant difference between the conditions appears with a reduced RER in the PAPCOND of 0.05 ± 0.02 (P < 0.01). Mean HR was significantly elevated in PAPCOND compared to CONTCOND by 4.0 ± 3.3 $b \cdot min^{-1}$ (P < 0.01). Despite being higher before the start of the trial blood lactate concentrations were lower upon completion of PAPCOND than after CONTCOND by 0.15 ± 2.72 $mM \cdot L^{-1}$, (P = 0.12). Post exercise differences in VO_2 during the first minute after the two trials were *unclear* and not significant (0.13 ± 1.82 $ml \cdot kg^{-1} \cdot min^{-1}$, P = 0.83). Differences in VO_2 over the 3 minutes post exercise were approaching significance (0.74 ± 1.15 $ml \cdot kg^{-1} \cdot min^{-1}$, P = 0.07) and a *likely small* increase following PAPCOND compared with CONTCOND (see Table 1).

	CONTCOND (mean ± SD)	PAPCOND (mean ± SD)	Difference of means (90% confidence limits)	Inference
Completion time (s)	315.2 ± 6.7	313.5 ± 6.3	-1.7 ± 2.1	possibly small ↓
Power output (W)	356.8 ± 21.7	361.9 ± 21.6	5.1 ± 6.1	possibly trivial ↑
Peak Force per pedal stroke (N)	317.6 ± 28.4	323.3 ± 26.0	5.7 ± 6.4	possibly trivial ↑
O_2 Uptake ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.7 ± 5.3	59.1 ± 5.1	1.4 ± 1.0 *	likely small ↑
Peak O_2 ($ml \cdot kg^{-1} min^{-1}$)	64.5 ± 5.6	65.2 ± 5.4	0.7 ± 0.7	possibly trivial ↑
CO_2 expiration ($ml \cdot kg^{-1} \cdot min^{-1}$)	66.5 ± 6.3	65.3 ± 5.1	-1.2 ± 1.5	possibly trivial ↓
RER	1.15 ± 0.54	1.11 ± 0.05	-0.05 ± 0.01 *	most likely small ↓
Heart rate ($b \cdot min^{-1}$)	168.7 ± 10.1	172.7 ± 9.8	4.0 ± 1.9 *	very likely small ↑
Blood lactate ($mM \cdot L^{-1}$)	17.1 ± 3.8	15.6 ± 3.1	-1.5 ± 1.6	likely small ↓
1 min post exercise VO2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	40.8 ± 3.4	40.9 ± 3.1	0.1 ± 1.1	unclear
3 min post exercise VO2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	23.7 ± 1.9	24.4 ± 1.4	0.7 ± 0.7	likely small ↑

*Statistically significant difference (P < 0.05).

Thresholds for inferences: <0.5% most unlikley, 0.5%-5% very unlikely, 5%-25% unlikely, 25-75% possibly, 75%-95% likely, >95% most likely.

Thresholds for the magnitude of the difference in each variable for small, moderate and large effects were determined as the pooled SD x 0.3, 0.9 and 1.6 respectively, with the exception of completion time.

Completion time thresholds for the magnitude of the difference for small, moderate and large effects were determined as the SD of the completion time of the top 10 finishers in a UCI world cup event x 0.3, 0.9 and 1.6 respectively.

Table 4. Differences in performance and physiological variables between PAPCOND and CONTCOND over the 4 km time trials.

Performance

ANOVA showed a significant main effect of split number (F = 24.6, P < 0.01) with split times generally increasing before a slight decrease in the final split time due to an end spurt. There were non-significant effects due to the condition (F = 1.8, P = 0.21) and the interaction between condition and split number (F = 0.5, P = 0.63). Similarly, analysis of PO revealed a significant main effect of split number (F = 20.2, P < 0.01) replicating the trend previously described for time, but not of condition (F = 2.4, P = 0.15) or interaction (F = 0.5, P = 0.62). Like those of PO and time, analysis of peak force also revealed a significant main effect of split number (F = 13.3, P < 0.01), but not of condition (F = 0.2, P = 0.85) or interaction (F = 0.5, P = 0.62). ANOVA of pulmonary gas exchange for VO_2 revealed that significant main effects were found on both split number (F = 874.7, P < 0.01) and condition (F = 8.4, P = 0.02), there was also a significant interaction between the main effects (F = 7.9, P < 0.01). VCO_2 was also significant over split number (F = 135.9, P < 0.01) with VCO_2 rising rapidly before peaking mid-trial, however neither the condition main effect (F = 2.3, P = 0.17), nor the interaction (F = 2.3, P = 0.13) were significant. RER was significant for both main effects of split number (F = 18.1, P < 0.01) and condition (F = 48.4, P < 0.01) as well as their interaction (F = 5.4, P = 0.01). Figure 2 depicts the significant interactions affecting VO_2 and RER. HR ANOVA demonstrated significant main effects for split number (F = 138.4, P < 0.01) and condition (F = 13.3, P = 0.01) with the trend replicating that of VO_2, the interaction between the two main effects was not significant (F = 1.7, P = 0.22).

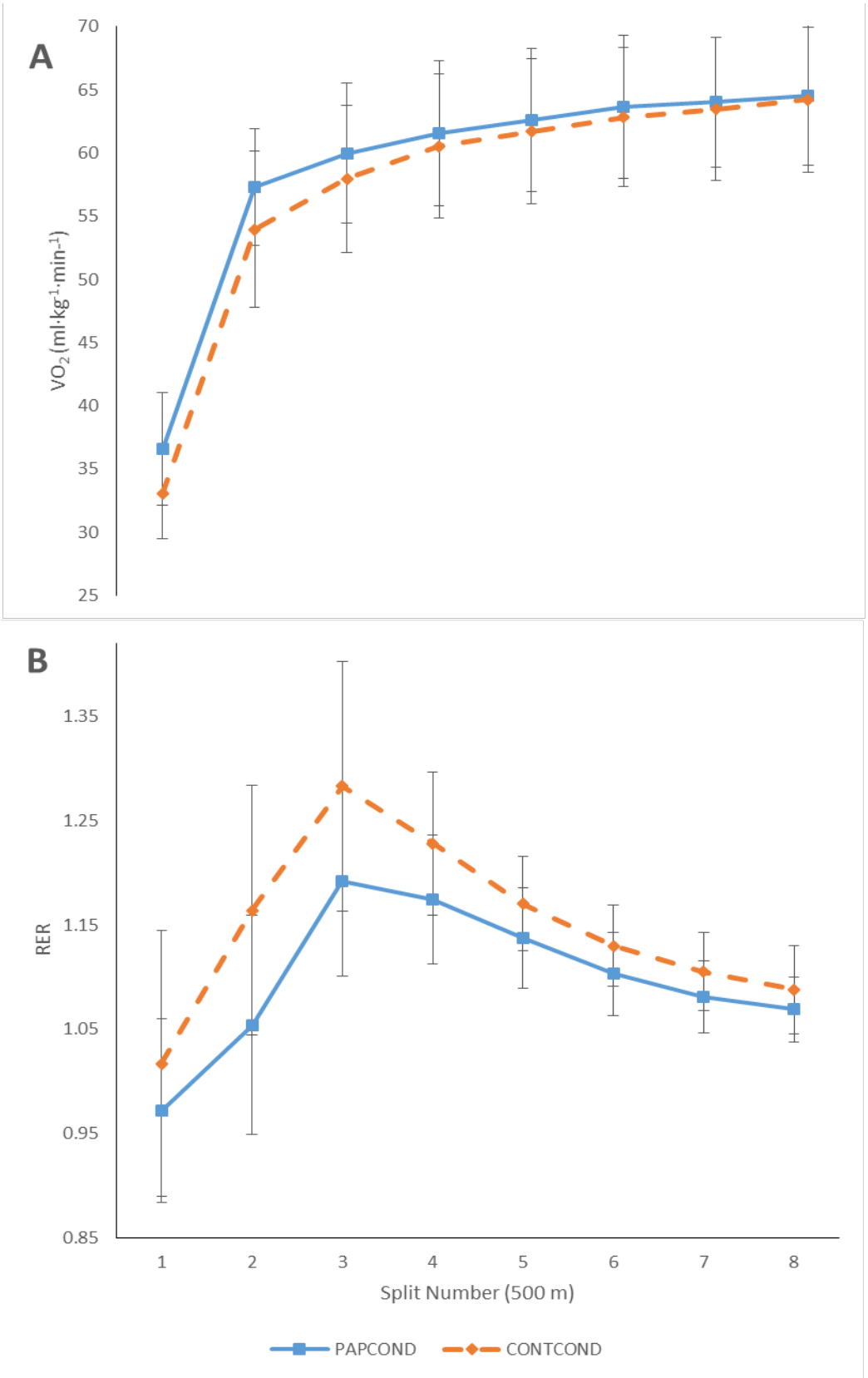

Figure 2. Changes in A) oxygen uptake and B) Respiratory Exchange Ratio for each 500 m split of the 4 km time trials. Differences ($P < 0.05$) were due to the main effects of condition; split number, and their interactions. Plot values are mean ± SD.

Post hoc analysis examined splits 1, 2 and 3 covering the first 1500 m of the trials. The analysis revealed that differences in performance and physiological measures due to the pre-trial conditions were greatest during the early stages of the trial (see Table 2).

Split 1				
	CONTCOND (mean ± SD)	PAPCOND (mean ± SD)	Difference of means (90% confidence limits)	Inference
Split time (s)	36.31 ± 2.43	36.07 ± 2.64	-0.24 ± 0.77	unclear
Power output (W)	451.6 ± 81.5	461.5 ± 91.5	9.9 ± 25.0	possibly trivial ↑
Peak Force per pedal stroke (N)	363.5 ± 46.2	368.5 ± 51.4	5.1 ± 13.1	possibly trivial ↑
O_2 Uptake ($ml \cdot kg^{-1} \cdot min^{-1}$)	33.0 ± 3.6	36.6 ± 4.4	3.5 ± 1.3 *	most likely small ↑
CO_2 expiration ($ml \cdot kg^{-1} \cdot min^{-1}$)	33.6 ± 5.9	35.5 ± 4.6	1.9 ± 2.1	likely small ↑
RER	1.02 ± 0.13	0.97 ± 0.09	-0.05 ± 0.04	likely small ↓
Heart rate ($b \cdot min^{-1}$)	140.1 ± 13.3	145.0 ± 14.4	4.9 ± 2.0 *	very likely small ↑

Split 2				
	CONTCOND (mean ± SD)	PAPCOND (mean ± SD)	Difference of means (90% confidence limits)	Inference
Split time (s)	38.32 ± 1.75	37.77 ± 1.28	-0.55 ± 0.72	possibly moderate ↓
Power output (W)	385.5 ± 47.4	399.3 ± 39.1	13.9 ± 17.4	possibly small ↑
Peak Force per pedal stroke (N)	332.7 ± 36.5	335.8 ± 8.5	3.0 ± 11.5	unclear
O_2 Uptake ($ml \cdot kg^{-1} \cdot min^{-1}$)	54.0 ± 6.2	57.3 ± 4.6	3.3 ± 1.9 *	very likely small ↑
CO_2 expiration ($ml \cdot kg^{-1} \cdot min^{-1}$)	62.9 ± 9.7	60.3 ± 7.3	-2.5 ± 3.7	possibly trivial ↓
RER	1.16 ± 0.12	1.05 ± 0.11	-0.11 ± 0.04 *	most likely small ↓
Heart rate ($b \cdot min^{-1}$)	162.9 ± 11.4	167.1 ± 11.4	4.2 ± 2.3 *	likely small ↑

Split 3				
	CONTCOND (mean ± SD)	PAPCOND (mean ± SD)	Difference of means (90% confidence limits)	Inference
Split time (s)	39.61 ± 1.11	39.26 ± 0.87	-0.35 ± 0.47	possibly small ↓
Power output (W)	349.9 ± 26.3	358.6 ± 21.4	8.8 ± 11.2	possibly small ↑
Peak Force per pedal stroke (N)	311.5 ± 29.3	316.6 ± 23.5	5.1 ± 5.6	possibly trivial ↑
O_2 Uptake ($ml \cdot kg^{-1} \cdot min^{-1}$)	58.0 ± 5.8	60.0 ± 5.5	2.0 ± 1.2	likely small ↑
CO_2 expiration ($ml \cdot kg^{-1} \cdot min^{-1}$)	74.2 ± 9.1	71.2 ± 6.6	-3.0 ± 3.0 *	likely small ↓
RER	1.28 ± 0.12	1.19 ± 0.09	-0.09 ± 0.04 *	most likely small ↓
Heart rate ($b \cdot min^{-1}$)	169.1 ± 10.8	173.5 ± 9.9	4.4 ± 3.4	likely small ↑

*Bonferroni corrected statistically significant difference ($P < 0.0167$).

Thresholds for inferences: <0.5% most unlikley, 0.5%-5% very unlikely, 5%-25% unlikely, 25-75% possibly, 75%-95% likely, >95% most likely.

Thresholds for the magnitude of the difference in each variable for small, moderate and large effects were determined as the pooled SD x 0.3, 0.9 and 1.6 respectively, with the exception of split time.

Split time thresholds for the magnitude of the difference for small, moderate and large effects were determined as the SD of 1/8th of the completion time of the top 10 finishers in a UCI world cup event x 0.3, 0.9 and 1.6 respectively.

Table 5. Differences in performance and physiological variables during splits 1 (0 - 500 m), 2 (500 - 1000 m) and 3 (1000 - 1500 m) between CONTCOND and PAPCOND.

Subjective perceptions of effort

Two way ANOVA results (condition x km completed) suggest no significant differences due to condition for RPE (F = 3.7, P = 0.86) and leg pain (F = 0.4, P = 0.55), but that the main effect of distance completed was significant for both measures; F = 137.0, (P < 0.01) and (F = 22.2, P < 0.01) for RPE and leg pain respectively. Both RPE and leg pain increased steadily from the start to the end of each trial (see Table 3). No significant interactions were found for either RPE (F = 1.8, P = 0.19) or leg pain (F = 0.2, P = 0.76).

RPE				
	CONTCOND (mean ± SD)	PAPCOND (mean ± SD)	Difference of means (90% confidence limits)	Inference
km 1	15.2 ± 1.3	15.5 ± 1.2	0.3 ± 0.7	unclear
km 2	16.4 ± 1.6	17.4 ± 0.5	1.0 ± 0.8	likely small ↑
km 3	17.9 ± 1.3	18.5 ± 0.7	0.6 ± 0.7	likely small ↑
km 4	19.5 ± 0.7	19.7 ± 0.5	0.2 ± 0.2	possibly small ↑

Leg Pain				
	CONTCOND (mean ± SD)	PAPCOND (mean ± SD)	Difference of means (90% confidence limits)	Inference
km 1	5.5 ± 0.8	5.8 ± 0.9	0.3 ± 0.7	unclear
km 2	6.3 ± 0.7	6.4 ± 1.1	0.1 ± 0.4	unclear
km 3	7.1 ± 1.2	7.1 ± 1.2	0.1 ± 0.4	unclear
km 4	7.8 ± 1.5	7.9 ± 1.3	0.1 ± 0.4	unclear

No statistically significant differences (P < 0.05).
Thresholds for inferences: <0.5% most unlikley, 0.5%-5% very unlikely, 5%-25% unlikely, 25-75% possibly, 75%-95% likely, >95% most likely.
Thresholds for the magnitude of the difference in each variable for small, moderate and large effects were determined as the pooled SD x 0.3, 0.9 and 1.6 respectively.

Table 6.Differences between CONTCOND and PAPCOND in subjective perceptions of RPE and leg pain after each km.

4. DISCUSSION

The main finding from this study was that a PAP-inducing warm-up produced non-significant performance improvements in terms of time and power output over the 4 km time trials of 1.7 s and 5.1 W respectively, when compared to a moderate intensity warm-up. As was hypothesised the performance improvements were mainly realised during the initial 1500 m of the time trial and accounted for a disproportionate 1.1 s of the small overall improvement. Whilst the improvements in finish and split times were related to the increases in PO, it is unclear if the peak forces applied to the pedals during each pedal stroke were responsible per se, or whether the increased forces necessary to generate the additional power were distributed through the pedal stroke. These findings are consistent with those of Barnes et al. (2015), in that prior exercise inducing PAP leads to an improvement in endurance performance in trained athletes, albeit with a smaller magnitude of improvement than the earlier study. Whilst Barnes et al. (2015) observed an improvement at the end of an incremental speed test, the present study revealed performance improvements were predominant in the early stages of the experimental trial. This supports the proposition by Sale (2004) that any muscle activity will induce PAP, and that once initiated in an endurance event the effects of PAP would be ongoing due to the exercise itself. Consequently the benefits of PAP inducement prior to the start of exercise would be most evident in the early stages of an event, as per the present study.

The performance changes in the present study were accompanied by associated changes in the physiological measures of VO_2, HR, and RER, along

with a significant increase in blood lactate concentration following the PAP-inducing warm-up. A moderate elevation of blood lactate has been linked with an improvement in subsequent endurance performance (Burnley et al., 2005; Jones, et al., 2003; Palmer et al., 2009; Wilkerson et al., 2004), possibly due to an associated increase in intra-muscular acidosis protecting against fatigue (Jones et al., 2003). The present study supports these associations as blood lactate concentration was initially higher due to PAPCOND, before increasing to similar levels during both trials. It can therefore be assumed that the difference in muscle lactate concentration between the trials would have been greatest in the early stages of the exercise, and that this difference coincided with the stages exhibiting the greatest differences in performance.

In the present study increased blood lactate concentration after the PAP inducement corresponded with increased VO_2 and HR in the first 1500 m of the time trial, reflecting the associations found by Palmer et al. (2009) following self-paced and high intensity warm-ups. The increase in VO_2 seen during the early stages of the present study following the PAP-inducing warm-up is similar to the findings in many studies exhibiting improved performance following effective prior exercise (Burnley et al., 2001; Christensen & Bangsbo, 2015; Faisal, et al., 2009; Hajoglou et al., 2005; Palmer et al., 2009), so would appear to be a highly desirable effect from the PAP-inducing warm-up. Indeed moderate intensity warm-ups have been found to not cause an increase in VO_2 contribution, or improve performance when compared to no warm-up conditions (Jones et al., 2003). However, Hajoglou et al. (2005) used a different protocol for a moderate warm-up that did improve performance, although this protocol also increased

VO_2 during the early stages despite it being labelled as *easy*. The increased oxidative contribution observed during the first 1500 m should lead to either i) an increase in PO, or ii) a reduction in oxygen debt and the sparing of anaerobic contribution as seen by Rossiter et al. (2001). In this study accompanying the elevated VO_2 following PAPCOND was a reduced VCO_2, a significant reduction in RER and a non-significant increase in PO, indicating a combination of the two effects was evident during the initial stages. VO_2 remained slightly higher for the remainder of the PAPCOND trail in comparison to CONTCOND, indeed 8 out of the 10 participants reached a greater VO_{2peak} in the former. The relationship between VO_2 and PAP has only been examined by Barnes et al. (2015) who found a lower oxygen cost following PAP-inducement due to improved efficiency in sub-maximal running, conversely this study resulted in a higher VO_2 as described above. This discrepancy is likely to be down to the differences in intensity where VO_2 was measured, with the supra-maximal exercise in this study eliciting a VO_{2peak} at or very close to the individuals $VO_{2max.}$ The additional oxygen cost aligns with both the increased calcium sensitivity and increased neural excitability mechanisms purported as the reasons behind PAP (Anthi et al., 2014; Hodgson et al., 2014; Sale, 2002), as both mechanisms would increase muscle activity in order to increase the RFD, resulting in an increased energy cost. Indeed a PAP-inducing activity adhering to the Henneman size principal (Henneman, 1965) of motor unit recruitment would result in a greater energy demand.

Given the increased oxidative metabolism and the apparent sparing of anaerobic resources it is somewhat surprising that a significant difference in

end spurt was not evident. Quantifying the anaerobic contribution cannot be done by measurement and calculations of the anaerobic contribution in supra-maximal exercise contains major sources of error (Palmer et al., 2009), hence the inferences into anaerobic contribution in this study are drawn from pulmonary gas exchanges and RER previously mentioned. It is possible that pacing cues and effort perception prevented any end spurt in either trial until the final seconds regardless of remaining anaerobic capacity. Pacing strategies were self-selected yet remained consistent for each individual between the two trials (see appendix 2). Adherence to a preferred strategy along with an RPE that increased throughout each trial may have restricted the end spurt more so than the availability of anaerobic resources. Instantaneous performance measures were withheld from the participants, however the sound from the airbrake of the Wattbike offered continuous feedback of any change of cadence or power. This feedback could also have influenced pacing and consequently the anaerobic contribution, particularly in the latter stages of the trial as the participant's focus may have been on maintaining cadence rather than increasing it.

Another factor which may have limited the effect of the PAP-inducement in this study was the optimisation of the PAP effect. Whilst training status (Hamada et al., 2000) and muscle fibre type (Hamada et al., 2003; Ryder et al., 2007) have been shown to influence the balance of PAP and fatigue (Chiu et al., 2003; Rassier & Macintosh, 2000), there is no precise method of optimising the parameters of PAP-inducement and recovery for individuals. Whilst the review by Wilson et al., (2013) offered guidelines which were applied to this study, the

guidelines were generated based mainly on studies reporting the success or failure to produce positive results due to PAP, rather than trials seeking an optimisation protocol. Despite the participants of the present study being of similar fitness, training background, and standard, the effectiveness of the PAP-inducements appeared to be individualistic. This may have been due to the magnitude of the positive PAP effect or the net balance for each individual. The magnitude of the PAP effect was not measured in this study and whilst doing so in future studies could help maximise the positive effects of PAP, it will not aid the optimisation of the PAP-fatigue balance.

The overall effect of this PAP-inducing pre-trial condition is similar to the effects found in other warm-up routines that have led to increased performance such as high intensity warm ups or repeated sprints (Burnley et al., 2005; Hajoglou et al., 2005; Jones et al., 2003; Palmer et al., 2009). In these studies elevated blood lactate concentrations were observed following the warm-ups, and elevated VO_2 and increased PO was observed in the early stages of the trials. Whether PAP is simply inducing the same effects as these types of warm-up or if can be used complimentary to existing routines in order to increase the benefits is a matter for future research. Investigations into complex warm-up routines incorporating PAP should also look at the individual responses to the PAP-fatigue balance and recovery times.

Conclusions

This is the first study to look specifically at PAP as a warm-up for an endurance cycling time trial, and the first to examine the effects of a PAP warm-up on

pulmonary gas exchange in a supra-maximal condition. The small improvement in completion time of 1.7 s and increase in power of 5.1 W whilst not significant could easily be a race winning improvement in a world where ever smaller margins make a difference. The effects of the PAP-inducement would appear to benefit the first 1500 m or 2 minutes of exercise before the on-going effort produces a PAP effect itself. The beneficial effects of PAP would appear to be linked to a pre-trial increase in lactate concentrations and subsequent elevation of VO_2 in the early stages of the event.

Practical implications

This study specifically attempted to exploit the effects of PAP in a cycle-specific manner for a cycling event. The effects would be most beneficial in the short endurance racing typically encountered in track racing, such as the individual pursuit, team pursuit or the kilo. Although this study used cycle ergometers to exercise a degree of control over the PAP-inducement in the laboratory, the essence of high power, slow cadence cycling in 10 s efforts could be reproduced with high resistance and high gearing on a turbo trainer and geared road bike, equipment which is already commonly used prior to track racing.

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APPENDICES

Appendix 1. – Additional Methodology

Data extraction for 500 m splits

Wattbike time, power & peak force analysis was achieved by connected a PC to the Wattbike head unit and importing the ride file into Wattbike Expert software following each 4km time trial. Within the Wattbike Expert application the “start analyse with first sample” was set on, then export analysis modules option was run to export the relevant data to a text file. Seven modules were selected for the export (Elapsed Time, Distance Total, Heart Rate, Force Peak, Avr Pace/1000m, Power Avr Power). The exported text file was then imported into a custom built excel spreadsheet in the Wattbike tab starting at cell A1. The completion time read from the Wattbike head unit was manually entered into cell N21. The spreadsheet automatically extracted the split times for each 500 m using interpolation of the distance total column. Using the cell references determined for each 500 m split the spreadsheet calculated the mean power and mean peak force for each split from the imported data. The cumulative times, split time, mean power and mean peak force for each split are displayed for each split in the array R20..Z28, with totals for the ride displayed in S30..Z31.

Gas Analysis data was exported as a text file for each 4 km time trial using the breath by breath export option from the Viasys software. The export included the covered the duration of the 4 km trial and a minimum of 3 minutes of post exercise gas exchange data. The text file was then imported into a custom built

excel spreadsheet on the gas tab page starting in cell A1. The imported file was manually checked for missing data in columns C, G & I (heart rate, VO_2 & VCO_2 respectively), if any missing data was encountered it was be rectified by interpolating using the values immediately above and below. The spreadsheet included calculations to give weighting to the analysis of each breath based on the time interval between breaths (Columns K…P). Using split and completion times from the Wattbike tab the spreadsheet used the weighted values to calculate means of Heart rate, VO_2 & VCO_2 foe each split. For the start and end of each split the calculations used the proportional values between breaths based on where the split time occurred between breaths. 500 m split parameters were produced in the range X3..Z11 for Heart rate, VO_2 & VCO_2. Post exercise VO_2 consumption and VCO_2 expiration was calculated for each of 3 minutes following the completion time taken from the Wattbike tab, using the weighted values. Values per minute, means, and totals are found in cells X16..AB20.

All split analysis files containing the imported raw data and calculated outputs for both the CONTCOND and PAPCOND trials by each participant are contained in the data disk.

						Measurements (mm)					Wattbike Settings						Lode setup				testing parameters				
Part No.	name	Consent	Pedal type	Saddle type	Crank length	A	B	C	D	seat rails	Seat height	layback	Bar height	bar for\aft	Magentic Brake	Air Brake	Seat height	layback	Bar height	bar for\aft	VO2max	60% of Vo2max	power@ 60% Vo2max	Max Power	70% max Power
0	LM	y	look keo	spec toupe (chester uni)	165	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1	6	n/a	n/a	n/a	n/a	50.2	30.12	150	1230	861
1	JJ	Y	look keo	spec toupe (chester uni)	172.5	770	70	580	660	1cm	20.5	6	14	4	1	4	13.5	flush wi	1	5	60.4	36.24	194	1090	763
2	JL	Y	time	spec toupe (chester uni)	172.5	755	20	555	605	1cm	18	1	8	6	1	4	12	flush wi	0	5	68.2	40.92	153	1173	821
3	JS	Y	look keo	spec toupe (chester uni)	172.5	798	92	595	640	1cm	23.5	4.5	11	5	1	low 4	14.5	flush wi	1.5	4.5	68.6	41.16	199	1131	792
4	JW	Y	shimano	spec toupe (chester uni)	172.5	?	?	?	?	1cm	25.5	1	14	6.5	1	4	15.5	flush wi	3	4	58.2	34.92	191	1056	739
5	AC	Y	Speedplay	spec toupe (chester uni)	172.5	765	60	570	610	1cm	19.5	5	9	4.5	1	5	13	flush wi	1	5	56.4	33.84	199	1293	905
6	RB	Y	look keo	spec toupe (chester uni)	170	?	?	?	?	1cm	12.5	1	6	1	1	4.5	10	2cm forv	3	7.5	68	40.8	174	1228	860
7	JN	Y	shimano	spec toupe (chester uni)	175	?	?	?	?	1cm	23	4	15	6.5	1	4	14.5	flush wi	3	5	53.1	31.86	141	1562	1093
8	AM	Y	look keo	spec toupe (chester uni)	172.5	795	75	585	660	1cm	23	5	14	6	1	5	14.5	flush wi	3	5	61.8	37.08	173	1380	966
9	SD	Y	Shimano	spec toupe (chester uni)	172.5	770	35	555	600	1cm	21	1	10	6.5	1	4	13.5	3cm forv	2	4.5	61	36.6	160	1166	816
10	RW	Y	time	adamo	170	?	?	?	?	na	15	0	0	2.5	1	9.5	11.5	mid poi	2	7.5	64.9	38.94	163	894	626
11	JD	Y	shimano	spec toupe (chester uni)	172.5	?	?	?	?	1cm	19	1	10	6.5	1	4.5	13	3cm forv	2	4.5	62.8	37.68	163	1327	929
															1							0			0
															1							0			0
															1							0			0
															1							0			0

measurements

A	BB to top of saddle
B	tip of saddle to BB horizontal distance
C	tip of saddle to centre of bars
D	BB to centre of bars vertical distance

Appendix 2. – Additional Results

See data disk for all raw data, 500 m split data extracts and statistical results and MBI calculations.

Appendix 3. – Materials

Ethics approval form

Faculty of Life Sciences
Research Ethics Committee

frec@chester.ac.uk

05/05/2015

Alan Chorley
45 Westcliff Gardens
Appleton

Dear Alan

Study title: **A study to determine the performance effects of post-activation potentiation in a 4km endurance cycling time trial in trained endurance cyclists.**
FREC reference: **1028/15/AC/SES**
Version number: **1**

Thank you for sending your application to the Faculty of Life Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	1	March 2015
Appendix 1 – List of References	1	March 2015
Appendix 2 – Summary CV for Lead Researcher	1	March 2015
Appendix 4 – Participant Information Sheet [PIS]	2	April 2015
Appendix 5 – Participant Consent Form	2	April 2015

Appendix 6 – Risk Assessment	1	March 2015
Appendix 3 – Additional researcher CV	1	March 2015
Appendix 7 – Pre-test questionnaire*	2	April 2015
Appendix 8 - Data Collection Procedures	1	April 2015
Response to FREC request for further information or clarification		April 2015

*Delete Q7 as all participants are male.

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Dr. Stephen Fallows
Chair, Faculty Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FREC Representative

Participant information form

Participant information sheet

Can Post Activation Potentiation during a warm-up lead to a performance improvement in endurance cycling?

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

What is the purpose of the study?
This purpose of this research is to investigate whether Post Activation Potentiation, or PAP as it is often known, can lead to a performance improvement in an endurance cycling event. PAP is the phenomenon whereby the performance of a muscle is enhanced by its recent activity.

This study will examine the effects of PAP on trained endurance cyclists as part of a pre-race strategy, by including short duration heavy resistance cycling at the end of a warm up, prior to a 4 km time trial, compared to the same warm-up that does not include PAP inducement. The aim is to detect any performance advantage due to PAP and to explain where that advantage comes from.

Why have I been chosen?
The study requires trained endurance cyclists. This is because it is hypothesized that the relevant muscles will have certain characteristics such as fatigue resistance and speed on contraction that could benefit from the PAP conditioning.

You have been chosen as it is expected that you would meet the selection criteria of being male aged 20-45 years, an experienced cyclist (who has trained for at least 5 years, or competed for at least 2 years) who currently trains ≥ 3 times per week for ≥ 180 minutes per week, and have a VO_{2max} ≥ 55 ml/kg/min.

Do I have to take part?
It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect you in any way.

What will happen to me if I take part?
You will be asked to attend the University's Human Performance Laboratory for 4 sessions. These will consist of a baseline testing session, a habituation session, and two experimental sessions, within a period of 4-11 days. The baseline and habituation sessions can be combined into a single visit if desired.

The baseline testing session will involve certain physiological tests to determine parameters for the later tests, including maximum aerobic and anaerobic efforts. The other 3 sessions will include easy warm-ups, the 3 x 10 seconds heavy resistance PAP conditioning, and a 4km time trial, all on static bikes.

Lab sessions are likely to last up to 2 hours for the baseline testing, and up to 1 hour for the others.

What are the possible disadvantages and risks of taking part?
The sessions will include tests to exhaustion. Expired air will be monitored by the wearing of a face mask covering the mouth and nose. Lactate testing will involve testing a small drop of blood after a fingertip pin prick. Any or all of these may be considered a discomfort, however there will be no lasting effects from any of the tests or sessions.

You will also be asked to adhere to certain requests about alcohol and caffeine consumption, meals and exercise prior to the sessions.

What are the possible benefits of taking part?
As an experienced cyclist you may be interested in learning about your own physiological make-up. The testing will include determining your individual values of VO_{2max} and lactate thresholds, together with their corresponding heart rate and power values. These values are often used by cyclists in their own training regimes. Depending upon the study's findings and your own response to the PAP, you may also be able to improve your own pre-race strategy. You will of course be contributing to the wider development of knowledge, specifically if, how and why PAP can be advantageous to cycling.

What if something goes wrong?
If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of the Faculty of Life Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, 01244 513055.

Will my taking part in the study be kept confidential?
All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the research will have access to such information.

What will happen to the results of the research study?
The results will be written up into a dissertation for my final project of my MSc. Individuals who participate will not be identified in any subsequent report or publication.

Who is organising the research?
The research is conducted as part of a MSc in Sport & Exercise Sciences within the Department of Sport and Exercise Sciences at the University of Chester. The study is organised with supervision from the department, by Alan Chorley, an MSc student.

Who may I contact for further information?
If you would like more information about the research before you decide whether or not you would be willing to take part, please contact:

Alan Chorley. 1428583@chester.ac.uk.

Thank you for your interest in this research.

Informed consent form

Title of Project: A study to determine the performance effects of post-activation potentiation in a 4 km endurance cyclng time trial in trained endurance cyclists

Name of Researcher: Alan Chorley

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without my legal rights being affected.

3. I agree to take part in the above study.

_____	_____	_____
Name of Participant	Date	Signature

Researcher	Date	Signature

1 for participant; 1 for researcher

Health questionnaire

Pre-test Questionnaire

A study to determine the performance effects of post-activation potentiation in a 4 km endurance cyclng time trial in trained endurance cyclists

Researcher*: Alan Chorley*

Name:_____ Test date:_____

Contact number:_____ Date of birth:_____

In order to ensure that this study is as safe and accurate as possible, it is important that each potential participant is screened for any factors that may influence the study. Please circle your answer to the following questions:

1. Has your doctor ever said that you have a heart condition *and* that you should only perform physical activity recommended by a doctor? YES/NO

2. Do you feel pain in the chest when you perform physical activity? YES/NO

3. In the past month, have you had chest pain when you were not performing physical activity? YES/NO

4. Do you lose your balance because of dizziness *or* do you ever lose consciousness? YES/NO

5. Do you have bone or joint problems (e.g. back, knee or hip) that could be made worse by a change in your physical activity? YES/NO

6. Is your doctor currently prescribing drugs for your blood pressure or heart condition? YES/NO

7. n/a n/a

8. Have you injured your hip, knee or ankle joint in the last six months? YES/NO

9. Do you know of any other reason why you should not participate in physical activity? YES/NO

Thank you for taking your time to fill in this form. If you have answered 'yes' to any of the above questions, unfortunately you will not be able to participate in this study.

Bike fit collection form

Title of Project: A study to determine the performance effects of post-activation potentiation in a 4 km endurance cyclng time trial in trained endurance cyclists

Name of Researcher: Alan Chorley

Bike Setup & configuration

Which pedal type do you use? _____

What Crank Length do you normally ride? _____

Do you wish to use your own saddle (if so please state model) _____

_____

Please note the following measurements with reference to the attached bike-fit diagram.

Measurement

A -Centre of bottom bracket to top of saddle (taken in line through the seat post) _____

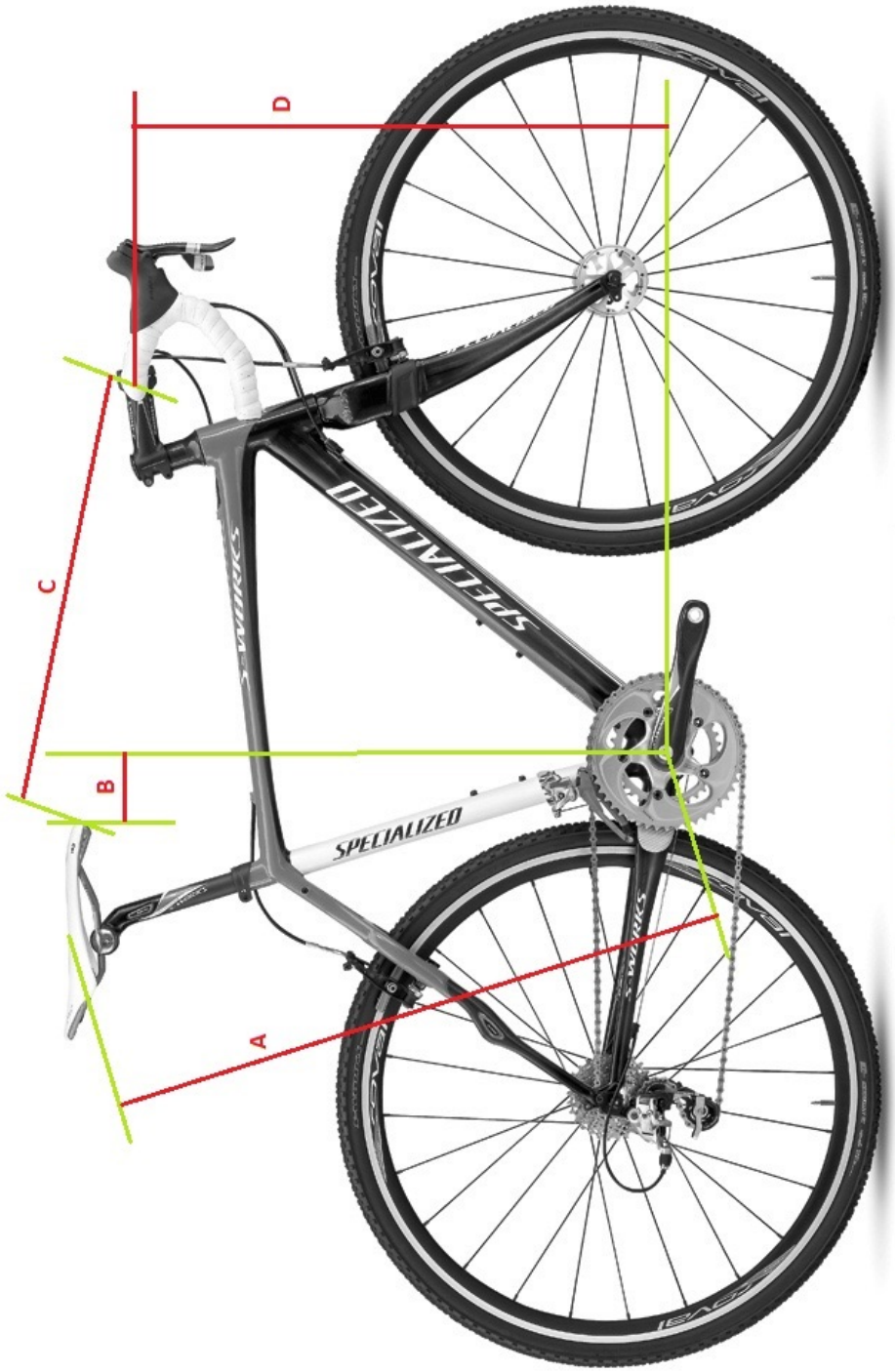
B –Horizontal distance from the tip of the saddle to the centre of bottom bracket _____

C –Tip of saddle to centre of handlebars (via the shortest direct line) _____

D –Vertical distance from centre of bottom bracket to centre of handlebars _____

* Please bring pedals, shoes with appropriate cleats and saddle (if required) to all sessions unless informed otherwise.

Bike fit diagram



	measurements
A	BB to top of saddle
B	tip of saddle to BB horizontal distance
C	tip of saddle to centre of bars
D	BB to centre of bars vertical distance

Laboratory testing schedule

June

Fri 19th (6pm) - Partipant#1 -baseline

Fri 26th (1pm) - Partipant#1 -trial1

Fri 29th (4pm) - Partipant#1 -trial2

July

Fri 3rd (3pm) - Partipant#2 -baseline

Sat 4th (11am) - Partipant#3 -baseline

Mon 6th (7pm) - Partipant#3 -#1 \Partipant#2 trial1

Thu 9th (7pm) - Partipant#3 -#2 \Partipant#2 trial2

Tue 14th (10am) -Partipant#4 -baseline

Thu 16th (5.30pm) - Partipant#4 - trial1

Fri 17th (2pm) - Partipant#5 –baseline \ Partipant#4 - trial2

Mon 20th (9.30am) - Partipant#6 baseline \ Partipant#5 -trial1

Wed 22nd (9.30am) - Partipant#5 -trial2 \ Partipant#6 trial1

Thus 23rd (9.30am) - Partipant#6 trial2

Tue 28th (4pm) - Partipant#7 – baseline \ Partipant#8 - baseline

Fri 31st (5pm) - Partipant#8 - trial1

August

Sat 1st (3pm) - Partipant#8 - trial2 \ Partipant#9 - baseline

Mon 3rd (4pm) - Partipant#7 - trial1 \ Partipant#9 - trial1

Tue 4th (4pm) - Partipant#7 - trial2 \ Partipant#9 - trial2

Mon 10th (10am) - Partipant#10 - baseline

Mon 17th (10am) - Partipant#11 - baseline

Tue 18th (10am) - Partipant#10 - trial1

Wed 19th (10am) - Partipant#10 - trial2 \ Partipant#11 - trial1

Thu 20th (10am) - Partipant#11 - trial2

Trials days apart:

(#1)-3, (#2)-3, (#3)-3, (#4)-1, (#5)-2, (#6)-1, (#7)-1, (#8)-1, (#9)-1, (#10)-1