Edwards, A. and McCormick, A. (2017) Time perception, pacing and exercise intensity: maximal exercise distorts the perception of time. Physiology & Behavior, 180. pp. 98-102. ISSN 0031-9384.

https://doi.org/10.1016/j.physbeh.2017.08.009

Title: Time perception, pacing and exercise intensity: maximal exercise distorts the perception of time

Authors: Edwards AM[1-2] & McCormick A[1]

Affiliation: [1]University of St Mark & St John, Plymouth, UK. [2]James Cook University, Sport & Exercise Science, Cairns, AUSTRALIA

Correspondence:

Professor Andrew M. Edwards
Dean, Faculty of Sport & Health Sciences
University of St Mark & St John
Plymouth, Devon
UK

Short title: Time perception is distorted by exercise

Keywords: Fatigue; Perception; Endurance; Sprint; Rowing; Cycling

Word count: 2948

Tables: 1

Figures: 4

Abstract

Introduction: Currently there are no data examining the impact of exercise on the perception of time which is surprising as optimal competitive performance is dependent on accurate pacing using knowledge of time elapsed. **Methods:** With institutional ethics approval, 12 recreationally active adult participants (f=7, m=5) undertook both 30s Wingate cycles and 20min (1200s) rowing ergometer bouts as short and long duration self-paced exercise trials, in each of three conditions on separate occasions: 1) light exertion: RPE 11, 2)heavy exertion: RPE 15, 3) maximal exertion: RPE 20. Participants were unaware of exercise duration and were required to verbally indicate when they perceived (subjective time) 1) 25%, 2) 50%, 3) 75% and 4) 100% of each bout's measured (chronological) time had elapsed. **Results:** In response to the Wingate task, there was no difference between durations of subjective time at the 25%, nor at the 50% interval. However, at the 75% and 100% intervals, the estimate for the RPE 20 condition was shortest (P<0.01). In response to rowing, there were no differences at the 25% interval, but there was some evidence that the RPE 20 condition was perceived shorter at 50%. At 75% and 100%, the RPE 20 condition was perceived to be shorter than both RPE 15 (P=0.04) and RPE 11 (P=0.008) conditions. **Conclusion:** This study is the first to empirically demonstrate that exercise intensity distorts time perception, particularly during maximal exercise. Consequently external feedback of chronological time may be an important factor for athletes undertaking maximal effort tasks or competitions.

Introduction

Recent research has investigated the role of perception, decision making and perceived exertion of individuals in response to timed exercise (Smits et al., 2014), but there is currently limited information on whether or not exercise influences the perception of time elapsed (Lambourne 2012). It is known that perception of time (subjective time) is manipulable and distortable under certain circumstances (Eagleman, 2005) but the impact of different exercise intensities on perception of time is as yet unexplored. This is surprising as investigation of temporal illusions help to expose the underlying neural mechanisms of time perception, which in turn is critical for accurately pacing human performance (Abbiss et al., 2016).

It has previously been shown that during dangerous incidents events pass in slow (perceptual) motion as if time has slowed down (Eagleman, 2005; Morrone et al., 2005). In practical terms this means that as danger increases, the subjective perception of time elapsed decreases (shrinks) due to greater than usual sensory awareness in a given period of time; hence measured (chronological) time runs slower than subjective time, giving the impression that ‘real-time’ has slowed. This effect has been neatly demonstrated in response to a task whereby participants were required to judge when 5s was elapsed ‘in danger’ and ‘no danger’ conditions (Langer et al., 1961). In the ‘no danger’ condition, the time estimate was 4.11s while it was 3.52s ‘in danger’ meaning that participants’ perception of time was furthest from 5s chronological time in the ‘in danger’ condition. This effect may be due to many factors akin to a fight or flight type response, not limited to increased arousal, anxiety and heightened emotions whereby experiences and sensory awareness is more densely packed during the frightening situation (Eagleman, 2005; Jansen et al., 1995). It is possible time distortion occurs in response to exercise, particularly during high intensity, self-regulated exercise where physical discomfort is significant (Edwards & Polman, 2013) and motivation is a key component in sustaining effort while regulating performance (McCormick et al., 2015).

The perception of time is part of human experience, yet its neural basis is still largely unknown (Brown, 2008). However, it is evident that in both short and long duration activities, as judged according to their perceived duration, they may be regarded as too long or as not lasting long enough. In cases where a person is working on an enjoyable attention-demanding task, chronological time may appear to pass quickly, but if working on a less pleasurable attentional-demanding task, it seems to pass slowly (Wittmann & Paulus, 2008). Other situations involving a heightened temporal awareness, such as anticipation, boredom, and impatience, appear to produce an apparent lengthening (or slowing down) of chronological time (Fraisse, 1984). Thus, sensory awareness of time is an outcome of intricacies between specific cognitive functions and momentary mood states (Wittmann, 1999).

There are currently few studies that have examined time perception and exercise parameters, which is surprising when considering the recent increase in literature related to brain regulation and pacing of performance (Abbiss et al., 2016; Edwards & Polman, 2013). However, one study showed that an acute response to exercise is to perceive time intervals to elapse more slowly, speculating that this is perhaps due to an increased internal pacemaker speed (Lambourne et al., 2012). Several other studies have examined the related concept of distance perception when experiencing exercise-induced, physical fatigue. For example, the perception of distance and slant appear to be influenced by the anticipated effort of exercise. Specifically, people have been shown to judge distances to be further when they were wearing a heavy backpack, compared to when they were not wearing a backpack (Proffitt et al., 2003). Similarly, hills appear steeper, requiring more effort to walk up them when wearing a heavy backpack, when fatigued from exercise, when of low fitness, or when elderly or in declining health (Bhalla & Proffitt, 1999). Of studies that have attempted to relate heart rate to time estimates before and after physical exercise, these have found no relationship (Bell & Provins, 1963; Schaefer & Gilliland, 1938) or weak associations (Osato et al., 1995). However no studies have yet compared subjective time estimates in response to exercise as a measure of pacing and particularly whether these differ according to the level of work undertaken. One study found that pharmaceutical aids, which either stimulated or inhibited the central or peripheral sympathetic nervous system, led to an increase or decrease in heart rate and breathing rate and an accompanying relative under- or over estimation of 4s intervals of exercise, respectively (Hawkes et al., 1962). The relative distortion of time intervals from that study may be interpreted as resulting from a sense of greater time elapsed compared to chronological time. This could be a function of an internally perceived 'clock'. If this is the case, it seems likely that arousal state, the environment and external conditions may influence internal neural perceptions of time (Wittmann & Paulus, 2008).

The purpose of this study was to examine whether or not differential, self-selected exercise intensities influenced the perception of time elapsed during both short duration and endurance exercise. Specifically, the experiment tested the hypothesis of whether maximal exercise distorts the perception of time.

Methods

Participants:

Twelve healthy adults agreed to participate in the study (table 1). All were informed of the procedures in advance of the study and informed consent was provided prior to any data collection in accordance with the Institution's Research Ethics Committee and the Declaration of Helsinki.

Experimental Design:

Participants were required to visit the laboratory on 4 occasions. On the first visit, baseline anthropometric data were collected (Table 1), also including an incremental cycling test to volitional exhaustion (25W/min) on a cycle ergometer (Lode, Groningen, Netherlands) for the assessment of maximal oxygen uptake (VO_2 max). Following a full recovery, participants completed initial familiarisation trials. During these familiarisation trials, participants completed a 30s Wingate and a 1200s rowing task and were able to see time elapsed on a visual display and were alerted to when 25%, 50%, 75%, and 100% of each bout's duration (chronological time) was completed. In subsequent familiarisation trials on the same day, participants completed a 30s Wingate and a 1200s rowing task but were blinded as to bout duration and were required to verbally identify (subjective time) when they perceived 25%, 50%, 75% and 100% of each bout had been completed in response to sustaining RPE 11 (light).

Following familiarisation, all 12 participants visited the laboratory on three further occasions in which they undertook 2 physical tasks: 1) a 30s Wingate task followed by a 30min passive recovery before completing 2) a 1200s rowing ergometry task. The Wingate and rowing tasks were each completed in 3 self-paced conditions based on pre-defined ratings of perceived exertion performed in random orders, with the caveat that trial exertion conditions differed on each occasion (i.e. no light, followed by light trials or maximal, followed by maximal trials): 1) light exertion (RPE 11), 2) heavy exertion (RPE 15), 3) maximal exertion (RPE 20). Participants were unaware of time elapsed in all bouts and were required on each occasion to verbally indicate subjective time estimates of when 1) 25%, 2) 50%, 3) 75%, and 4) 100% of each bout's duration had elapsed, for which they received regular verbal prompts from an automated voice recording while data collectors remained out of sight and silent. The recorded prompts were continuously cycled for the 30s Wingate task, while for the longer rowing trial they were delivered towards the end of each of the first minute in each 25% sector of the 1200s bout.

Physiological Assessments:

Gas exchange and minute ventilation were continuously recorded breath-by-breath at the mouth during the incremental cycling test for the assessment of VO_2max. Gases were continuously drawn through a capillary line and analysed for O_2 and CO_2 concentrations by fast-response analysers utilising principles of electrochemical reactions for the detection of O_2 and absorption by CO_2 of appropriate wavelengths of infrared light (Cortex MetaMax 3B, Cortex Biophysik, Germany). The system was calibrated before and verified after each test with standard calibration gases. Heart rate was monitored beat to beat and collated into 5s averages while power output was collected from the cycle (Monark 894E, Sweden) and rowing ergometers (Concept 2 D, Nottingham, UK) for evaluation of physical performances.

Time Estimates and Psychological Assessments:

All participants were required to pace the 30s (cycle) and 1200s (rowing) exercise bouts in accordance with that of a specific rating of perceived exertion (RPE). Self-selected exercise in response to a 'clamped' RPE was determined the most appropriate means of differentiating the exercise bouts so to appropriately individualise work rates according to participants' fitness and experience (Edwards et al., 2016). This was undertaken by using Borg's 6-20 RPE scale at three different ratings corresponding to RPE 11 (light) RPE 15 (heavy), and RPE 20 (maximal) in accordance with similar experiments (Edwards et al., 2016). Participants were reminded at regular intervals via an audio recording that they were required to verbally indicate when they perceived 25%, 50%, 75%, and 100% of each bout had been completed. Their responses were audio recorded and time aligned to the task duration for accurate assessment of time estimates. Participants were requested to cease exercise at 100% of chronological time unless their subjective 100% time estimate had not yet been stated to facilitate over and under estimations.

Statistical Analysis:

Data are shown as mean (SD). Two-way analysis of variance for repeated measures (RPE trials x time) was used to establish whether any significant differences existed between the subjects' estimates of perceived duration at 25%, 50%, 75%, and 100% of measured duration across the three conditions for 1) Wingate task and 2) rowing ergometry. When differences were indicated by ANOVA, a post hoc Tukey's honest significant difference test was used to determine where they lay. The level of significance in this study was set at $p<0.05$.

Results

30s Wingate Trials:

In response to the short duration exercise challenge (30s Wingate trials), the cohort completed the RPE 20 bout with the greatest peak power output (627.6 ±127.2W), which was significantly higher than both the RPE 15 trial (560.2 ±173.2W) (P=0.035) and the RPE 11 trial (489.7 ±149.7W) (P=0.007).

The distribution of power output identified that peak power was attained within the first 3s of each bout across all conditions (Figure 1). Power output thereafter dissipated across the 30s duration of each task in a similar pattern.

Estimates of subjective time for the three Wingate tasks were not different between conditions at 25% of chronological time, nor at 50%. At 75% of chronological time, the RPE 20 bout was perceived to be shorter compared to the RPE 11 condition (P=0.01) but not the RPE 15 condition (P=0.07), while at 100% of chronological time (30s), the subjective time estimate for RPE 20 (25.6 ±1.1s) was significantly shorter than both RPE 15 (27.8 ±0.9) (P=0.01) and RPE 11 conditions (28.8 ±1.2s) (P=0.009; Figure 2).

Endurance Exercise:

In response to the endurance exercise (rowing ergometry), the RPE 20 trial resulted in the highest average power output (101.3 ±27.8W) across the 1200s bout compared to RPE 15 (80.6 ±16.6W) (P<0.01) and RPE 11 trials (59.3 ±11.3W) (P=0.006) (Figure 3). Pacing profiles of the RPE 20, 15 and 11 conditions demonstrated the highest power outputs were attained in the first sector (<300s), thereafter settling into relative steady state for the remainder of each bout. There was no significant evidence of an end spurt in any condition.

None of the rowing conditions differed in subjective time at 25% of chronological time or at 50% although there was a trend for shorter estimate in the RPE 20 condition compared with RPE 11 (P=0.08). At 75% and 100% of chronological time, RPE 20 was perceived to be shorter than both RPE 15 (P=0.04 and P=0.02) and RPE 11 (P=0.008 and P=0.005) conditions (Figure 4).

Retrospective rank order evaluation revealed that the RPE 20 condition to be the one in which time was perceived to pass slowest for both Wingate (P=0.03) and rowing exercise (P=0.02).

Discussion

This study is the first to demonstrate that the perception of time is significantly influenced by exercise intensity and associated perceived exertion. The higher the intensity of exercise, the more the perception of time appears to shorten in relation to the chronological time elapsed. This observation has similarity to previous findings that individuals perceive distance to be further (Pinheiro et al., 2016) in tasks of greater severity (Bhalla & Proffitt, 1999) although distortion of time perception has important implications for pacing and competitive performance if misjudgements occur, particularly in endurance events such as time-trials. In practical terms, our results indicate chronological time appears to be moving slower than expected at high intensity and it seems likely this is due to greater sensory awareness of physical discomfort during maximal effort exercise (Edwards & Polman, 2013). This is most akin to the fight or flight response whereby the adrenal medulla produces a hormonal cascade that results in the secretion of catecholamines and a subsequent state of hyperarousal (Jansen et al., 1995). Therefore experiences are densely packed into a shorter period than is objectively true during maximal exercise due to augmented physical arousal and awareness of the physical situation. The current experiment examined potential time distortion among recreationally active participants and it is possible that well-trained, experienced athletes may respond differently, particularly if they are accustomed to performing in an associative state. Therefore although exercise intensity appears to distort the perception of time, giving the sense that the external (chronological) clock moves slowly in high intensity exercise, the generalizability of the observation may be confined to the population examined.

Increasing awareness of physical discomfort during highly demanding exercise has previously been proposed to contribute to exercise intolerance, premature cessation of exercise, disengagement and lack of enthusiasm for sustaining maximal work for prolonged periods (Marcora, 2008). As the reasons for the cessation of exercise are complex and task dependent (Smits et al., 2014), it seems likely that neural regulation of performance is informed by physical factors such as depletion of metabolic fuel stores, limitations within muscle, delivery of O_2 to muscle, and other allied physiological factors (Edwards et al., 2016; St Clair Gibson et al., 2006). It has been proposed that these variables function in combination to inform the brain of factors contributing to the level of exertion a person is willing to endure for a given period of time (Edwards & Polman, 2013). The precise level of exercise intolerance could vary with the perceived importance of the activity, therefore depending heavily on task-related motivation (McCormick et al., 2015).

Although Wingate task performances are rarely considered in relation to effort levels beneath maximal, the participants in this study were able to successfully differentiate and scale their voluntary power outputs across conditions using the self-paced estimates of exertion in accordance with the RPE scale (Abbiss et al., 2015). The distribution of power output was consistent with typical maximal Wingate performances for peak power to be achieved in <3s and thereafter for a rapid and progressive dissipation of work over the 30s period (Edwards et al., 2016). In the early stages of the 30s bout, mean perceptions of time were similar across conditions although shorter than chronological time (Figure 2). At the 75% assessment interval, cadence had slowed substantially, fatigue had accumulated and inter-participant variance of time perception had to some extent reduced. The reduction of time estimate variance was most pronounced between participants in the RPE 20 condition, particularly at the 75% point meaning that estimates shorter than chronological time became consistently similar across the cohort. This resulted in shortening of subjective time at RPE 20 compared to the RPE 11 bout, an effect similar to that reported in response to unpleasant or dangerous experiences (Bell & Provins, 1963; Langer, et al., 1961). Nevertheless, this effect was only detectable between the RPE 20 and RPE 11 self-paced conditions, but not with the RPE 15 trial although trends are evident.

The endurance rowing task produced similar outcomes to that of the 30s Wingate task across conditions, whereby the early stages of the bout (25% and 50%) did not differentiate between conditions, meaning that low intensity exercise did not appear to significantly impact on the perception of time earlier in the trials. However, at 75% of duration there was statistical differentiation between conditions, with the maximal bout producing the shortest time perception. Therefore, the effect of exercise intensity on time perception was most pronounced in response to extended, endurance-type exercise although the mechanisms for this observation require further investigation.

Although the perception of time is not associated with a specific sensory system, it has been suggested that humans do have a mechanism to handle time perception by utilising a highly distributed system involving the cerebral cortex, cerebellum and basal ganglia (Rao et al., 2001). Several studies using neuroimaging techniques have isolated areas of brain activity while participants time their movements or estimate durations. These studies suggest a temporal processing mechanism may exist in the right prefrontal cortex (ventrolateral and dorsolateral areas) although this remains to be proven (Marcora, 2008; Rao et al., 2001). In addition, activation of basal ganglia are unclear in neuroimaging techniques, thus it is plausible yet unproven that dopamine modulation in right prefrontal areas might be the basis for a timekeeping mechanism (Lewis & Miall, 2006).

It seems intuitively unlikely that one mechanism or neural system is responsible for internal estimates of time (Brown, 2008). Despite time being an essential factor for understanding complex behaviour (Bell & Provins, 1963) including responses to exercise, the underlying processes are incompletely understood (Lewis & Miall, 2006). Future empirical evidence may indicate whether a neural system exists for the representation of time and which neurobiological mechanism causes the experience of time. Nevertheless, it is apparent from this study that the intensity of exercise distorts the perception of time, providing evidence that sensory time runs slowly in challenging, high intensity exercise. This provides important clues as to the regulatory mechanisms of physical performance.

Despite its importance to behaviour and perception, the neural bases of time perception in response to exercise remain largely unexplored. It is apparent the brain exploits knowledge of elapsed time to pace an exercise bout (Abbiss & Laursen, 2008; Abbiss et al., 2016; Edwards & Polman, 2013; Smits et al., 2014) and to prepare appropriate actions (St Clair Gibson et al., 2006). However, data from this study suggest sensory time estimates are manipulable by exercise intensity. As intensity of physical effort grows, it seems plausible that so too does increased sensory awareness due to hyperarousal (Jansen et al., 1995). This means a greater amount of neural information processing is likely in a shorter than usual time, thus making it appear as though more time has passed than is objectively true. This may have practical implications for the accurate pacing of races, whereby athletes could benefit from external reinforcements and feedback of chronological time elapsed in order to accurately judge the duration of the event, evaluate remaining physical resources and gain an optimal outcome. Nevertheless, as the experimental trials of this study were conducted on laboratory ergometers, it remains to be determined whether our findings relate to field-based competitive performances. Subjectively perceiving time has elapsed quickly in high intensity exercise therefore appears likely to be a reflection of greater than usual processing of unpleasant stimuli in a heightened state of physical discomfort although more work is required to clarify the generalisation of this observation across exercise scenarios.

Highlights:

- Exercise distorts the perception of time
- Exercise intensity differentially influences the perception of time
- High intensity exercise shortens subjective time, making chronological time seem slow
- Athletes undertaking maximal exercise or races may benefit from external reinforcement of chronological time to ensure optimal pacing.

References

1. Abbiss, C.R., & Laursen, P.B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, 38, 239-252.
2. Abbiss, C.R., Peiffer, J.J., Meeusen, R., & Skorski, S. (2015). Role of ratings of perceived exertion during self-paced exercise: What are we actually measuring? *Sports Medicine,* 45, 1235-1243.
3. Abbiss, C.R., Thompson, K.G., Lipski, M., Meyer, T., & Skorski, S. (2016). Difference in pacing between time-and distance-based time trials in trained cyclists. *International Journal of Sports Physiology and Performance,* 11, 1018-1023.
4. Bell, C.R., & Provins, K.A. Relation between physiological responses to environmental heat and time judgments. *J Exp Psychol.* 1963;66:572–579.
5. Bhalla, M., & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1076-1096.
6. Brown, S.W. (2008). Time and attention: Review of the literature. In Grondin S (Ed.), *Psychology of time*. Bingley, England: Emerald, 111−138.
7. Eagleman, D.M. (2005). Distortions of time during rapid eye movements. *Nature Neuroscience,* 8, 850–851.
8. Edwards, A.M., Deakin, G.B., & Guy, J.H. (2016). Brain and cardiorespiratory responses to exercise in hot and thermoneutral conditions. *International Journal of Sports Medicine,* 37, 779-784.
9. Edwards, A.M., & Polman, R.C.J. (2013). Pacing and awareness: brain regulation of physical activity. *Sports Medicine,* 43, 1057-1064.
10. Fraisse, P. (1984). Perception and estimation of time. *Annual Review of Psychology,* 35, 1−36.
11. Hawkes, G., Joy, R., & Evan, W. (1962). Autonomic effects on estimates of time: evidence for a physiological correlate of temporal experience. *Journal of Psychology,* 53, 183–191.

12. Jansen, A.S., Van Nguyen, X., Karpitskiy, V., Mettenleiter, T.C., & Loewy, A.D. (1995). Central command neurons of the sympathetic nervous system: basis of the fight-or-flight response. *Science,* 270, 644-650.
13. Lambourne, K. (2012). The effects of acute exercise on temporal generalization. The Quarterly Journal of Experimental Psychology, 65, 526-540.
14. Langer, J., Wapner, S., & Werner, H. (1961). The Effect of Danger upon the Experience of Time. *American Journal of Psychology,* 74, 94-97.
15. Lewis, P.A., & Miall, R.C. (2006). A right hemispheric prefrontal system for cognitive time measurement. *Behavioural Processes,* 71, 226–234.
16. McCormick, A., Meijen, C., & Marcora, S. (2015). Psychological determinants of whole-body endurance performance. *Sports Medicine*, 45, 997-1015.
17. Marcora SM. (2008). Do we really need a central governor to explain brain regulation of exercise performance? *European Journal of Applied Physiology,* 104, 929-931.
18. Morrone, M.C., Ross, J., & Burr, D. (2005). Saccadic eye movements cause compression of time as well as space. *Nature Neuroscience,* 8, 950 –954.
19. Osato, E., Ogawa, N., & Takaoka, N. (1995). Relations among heart rate, immediate memory, and time estimation under two different instructions. *Perceptual and Motor Skills,* 80:831–842.
20. Pinheiro, F. A., Santos, T. M., & Pires, F. O. (2016). Conscious distance monitoring and perceived exertion in light-deprived cycling time trial. Physiology and Behavior, 165, 211-216.
21. Proffitt, D.R., Stefanucci, J. Banton, T., & Epstein, W. (2003). The role of effort in perceiving distance. *Psychological Science*, *14*, 106- 112.
22. Rao, S.M., Mayer, A.R., & Harrington, D.L. (2001). The evolution of brain activation during temporal processing. *Nature Neuroscience,* 4, 317–23.

23. Schaefer, V.G., & Gilliland, A.R. (1938). The relation of time estimation to certain physiological changes. *Journal of Experimental Psychology,* 23, 545–552.
24. Smith, A., Taylor, E., & Lidzba, K. (2003). A right hemispheric frontocerebellar network for time discrimination of several hundreds of milliseconds. *Neuroimage,* 20, 344–350.
25. Smits, B.L.M., Pepping, G.J., & Hettinga, F.J. (2014). Pacing and decision making in sport and exercise: the roles of perception and action in the regulation of exercise intensity. *Sports Medicine,* 44, 763-775.
26. St Clair Gibson, A.C, Lambert, E.V., Rauch, L.H., & Noakes, T.D. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine,* 36, 705-722.
27. Wittmann, M. (1999). Time perception and temporal processing levels of the brain. *Chronobiology International,* 16, 17–32.
28. Wittmann M, Paulus MP. (2008). Decision making, impulsivity and time perception. *Trends in Cognitive Sciences*, 12, 7–12.

Competing interests:

There are no competing interests for this study

Acknowledgements:

This project was supported by an internal research grant. No external funds were sought for this experiment.

The author thanks the technical support officers and research students who participated in the successful completion of this project.

Table 1: Physical characteristics of the participants

Age	Height	Mass	VO_2max
21.3	147.4	61.7	41.0
±7.2	±52.6	±24.6	±11.7

(f = 7, m = 5)

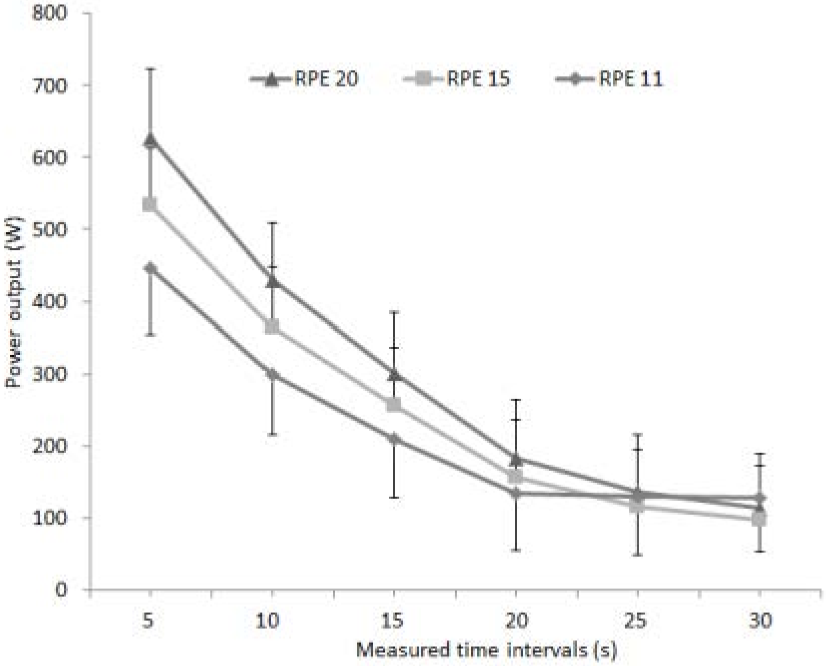
Figure captions:

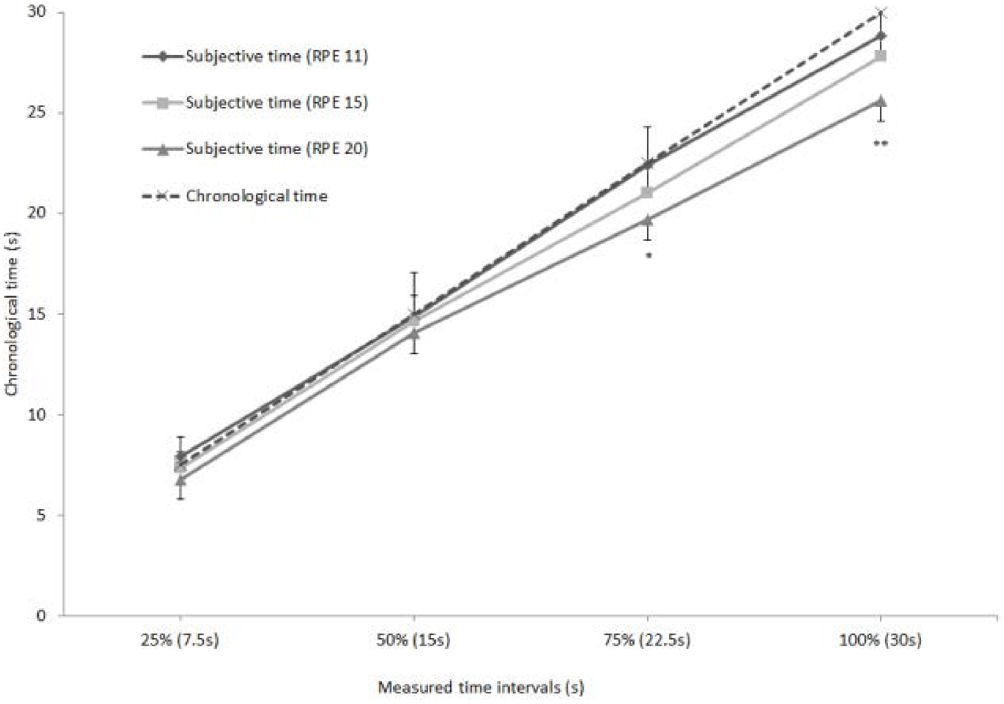
Figure 1. Mean (± SD) self-selected pacing profiles in response to 30s Wingate task across RPE 20 (maximal), RPE 15 (heavy) and RPE 11 (light) conditions.

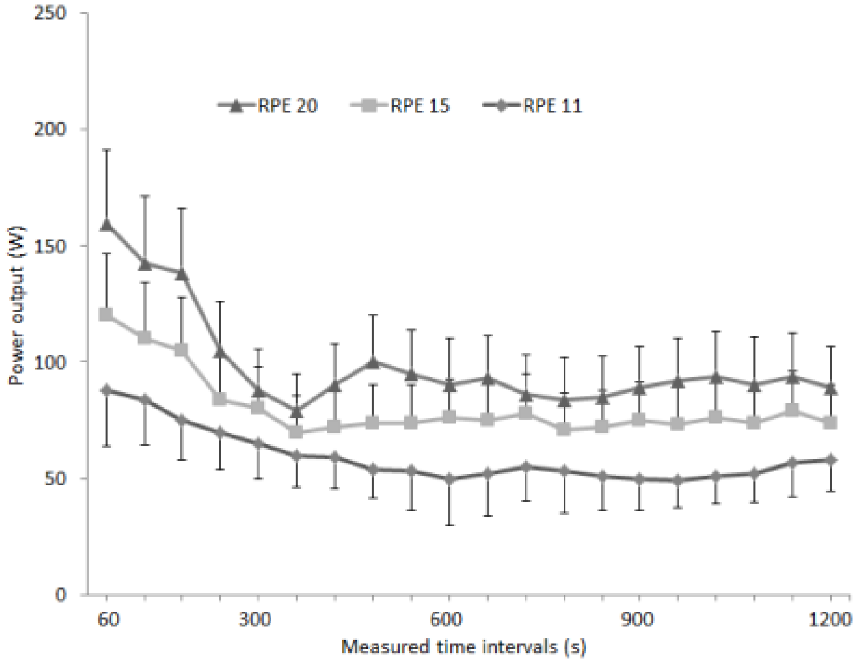
Figure 2. Subjective time estimates of the participants in response to 30s Wingate task at 25%, 50%, 75% and 100% of measured (chronological) time elapsed. * = significant difference between RPE 20 and RPE 11 conditions, ** = significant difference between RPE 20 and RPE 15 conditions.

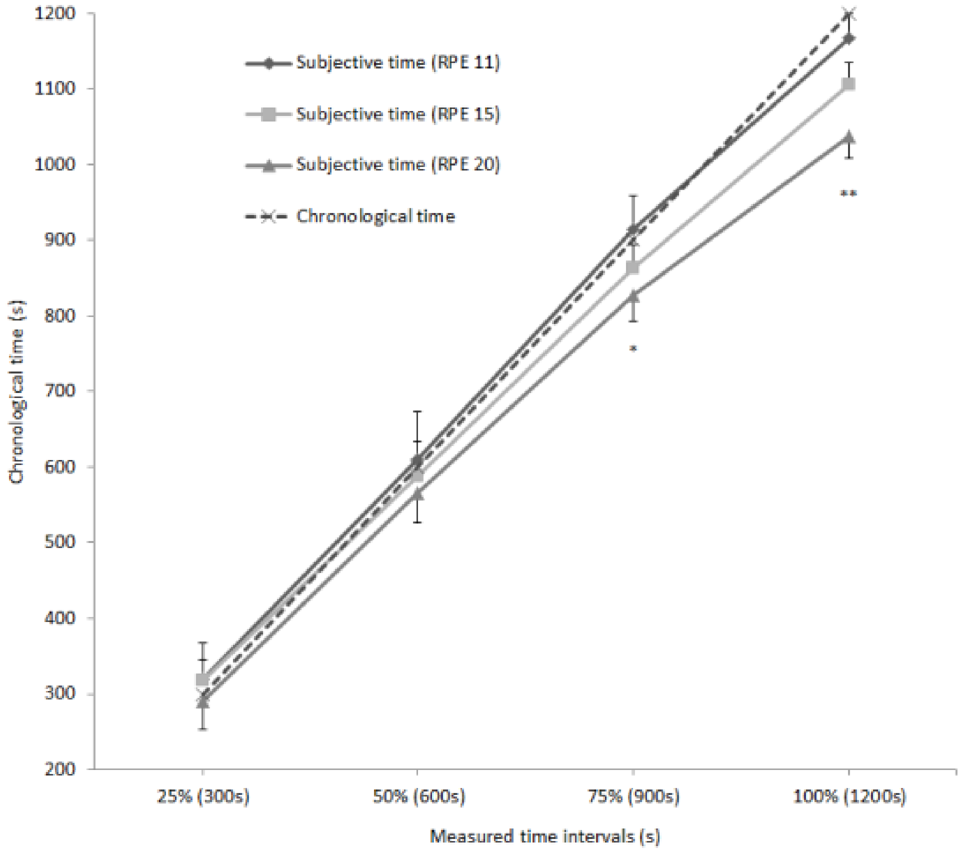
Figure 3. Mean (± SD) self-selected pacing profiles in response to 1200s rowing ergometer task across RPE 20 (maximal), RPE 15 (heavy) and RPE 11 (light) conditions.

Figure 4. Subjective time estimates of the participants in response to 1200s rowing ergometry task at 25%, 50%, 75% and 100% of measured (chronological) time elapsed. * = significant difference between RPE 20 and RPE 11 conditions, ** = significant difference between RPE 20 and RPE 15 conditions.


RPE 20
RPE 15
RPE 11
Power output (W)
800
700
600
500
400
300
200
100
0
5
10
15
20
25
30
Measured time intervals (s)


Subjective time (RPE 11)
Subjective time (RPE 15)
Subjective time (RPE 20)
Chronological time
Chronological time (s)
30
25
20
15
10
5
0
*
**
25% (7.5s)
50% (15s)
75% (22.5s)
100% (30s)
Measured time intervals (s)


RPE 20
RPE 15
RPE 11
Power output (W)
250
200
150
100
50
0
60
300
600
900
1200
Measured time intervals (s)


Subjective time (RPE 11)
Subjective time (RPE 15)
Subjective time (RPE 20)
Chronological time
Chronological time (s)
1200
1100
1000
900
800
700
600
500
400
300
200
*
**
25% (300s)
50% (600s)
75% (900s)
100% (1200s)
Measured time intervals (s)