Kent Academic Repository

Full text document (pdf)

Citation for published version

O'Grady, C, Passfield, Louis and Hopker, James G. (2021) Variability in submaximal self-paced exercise bouts of different intensity and duration. International Journal of Sports Physiology and Performance . ISSN 1555-0265. (In press)

DOI

Link to record in KAR

https://kar.kent.ac.uk/87830/

Document Version

Author's Accepted Manuscript

Variability in submaximal self-paced exercise bouts of different intensity and duration

Submission type: Original Investigation

Authors: Ciaran O'Grady[1], Louis Passfield [1,2], James G. Hopker[1]

1. Endurance Research Group, School of Sport and Exercise Sciences, University of Kent, UK.
2. Human Performance Lab, Faculty of Kinesiology, University of Calgary, Alberta, Canada.

Correspondence:
Mr Ciaran O'Grady
School of Sport and Exercise Sciences
University of Kent at Medway
Medway Building
Chatham, Kent
ME4 4AG
England
cmao3@kent.ac.uk
+44 (0)7904 597368

Running head: Effort-based exercise variability

Abstract word count: 241

Text-only word count: 3641

Number of figures and tables: 4 tables

References: 52

ABSTRACT

Purpose: The use of rating of perceived exertion (RPE) as a training intensity prescription has been extensively used by athletes and coaches. The individual variability in physiological response to exercise prescribed using RPE has not been investigated. **Methods:** Twenty well-trained competitive cyclists (18 = male, 2 = female, $\dot{V}O_{2max}$: 55.07 ± 11.06 $mL.kg^{-1}.min^{-1}$) completed 3 exercise trials each consisting of nine randomised self-paced exercise bouts of either 1, 4, or 8 minutes at RPE 9, 13, and 17. Within- (WAV) and between-athlete (BAV) variability in power and physiological responses were calculated using coefficient of variation (CV). Total variability (TV) = ratio of WAV and BAV. **Results:** Increased RPE saw higher power, HR, work, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, and ΔHHb ($P < .001$), and lower ΔTSI% and ΔO_2Hb ($P < .001$). At RPE 9, shorter durations resulted in lower $\dot{V}O_2$ ($P < .05$), and ΔTSI% decreased and ΔHHb increased as duration increased ($P < .05$). At RPE 13, shorter durations resulted in lower $\dot{V}O_2$, $\dot{V}_E$, and $\%\dot{V}O_{2max}$ ($P < .001$), higher power, HR, ΔHHb ($P < .001$) and ΔTSI% ($P < .05$). At RPE 17, power ($P < .001$) and ΔTSI% ($P < .05$) increased as duration decreased. As intensity and duration increased, WAV and BAV in power, work, HR, $\dot{V}O2$, $\dot{V}CO2$, and $\dot{V}E$ decreased, and WAV and BAV in NIRS increased. **Conclusions:** Self-paced intensity prescriptions of high effort and long durations result in greatest consistency on both a within-athlete and between-athlete basis.

KEYWORDS: endurance training, individual variability, effort-based training, cycling training, measurement error

INTRODUCTION

Perception of effort is defined as the intensity of subjective effort, stress, discomfort, and fatigue which is felt during exercise or physical activity [15,34]. The common method of measuring perception of effort is the rating of perceived exertion (RPE) scale [4] which is believed to be influenced by factors such as fatigue, effort, strain, discomfort, and/or pain [49]. It has been demonstrated that increased RPE is associated with increases in oxygen consumption, metabolic acidosis, ventilation, and heart rates [14,39]. The RPE scale is commonly used to record RPE whilst an individual is exercising [31] but can also be used as a tool to prescribe exercise intensity in the so-called ‘*production mode*’ which provides an exercise intensity continuum that exercising individuals can use to regulate their work rate or resistance [4,36].

When using RPE in production mode, it is unclear whether both the intensity of the RPE anchor and the duration of the work bout would influence the accuracy and reliability of the exercising individual to adjust their work rate or resistance to maintain a specified RPE level, or anchor. The reproducibility of this approach to exercise prescription has been investigated involving blind [5], child [17], and healthy participants [21]. It has been shown that when exercise intensity was prescribed using RPE in production mode during both low and high levels of exertion there is no difference in reliability in children when used with, or without, an anchoring protocol involving familiarisation with a low and high RPE workload before investigation [50]. Increased reliability using RPE in production mode after a series of trials has been demonstrated in blind men and women (maximal oxygen uptake [$\dot{V}O_{2max}$]; 5.2pp at RPE 9, and 6.8pp at RPE 11)[5] and children aged 7-10 years old (power output; 9.5pp in boys, 13pp in girls)[17] which may indicate a learning effect of using the scale in this manner. Nevertheless, in a large study of 2,560 Caucasian men and women, healthy individuals are able to accurately reflect heart rate and blood lactate response using RPE [43]. As duration and intensity are both known to impact an individuals' perception of effort it is therefore likely to impact upon reliability of the exercise intensity that is selected in response to a specific RPE anchor [45]. It has been demonstrated that increased intensity of perceptually regulated exercise results in increased reliability [21].

Traditionally, the prescription of exercise training intensities has been derived from standardised percentages $\dot{V}O_{2max}$ [24,29,30,38]. However, the inter-individual variability in performance that occurs during exercise prescribed in this manner is large [9,26,42,51,52]. The use of RPE in production mode may provide exercise practitioners with a useful tool to consistently prescribe exercise intensity. However, with limited research exploring the impact of duration on the reliability of perceptually regulated exercise [16,35], and no knowledge of the impact of changes in both duration and intensity on reliability, the interaction is unknown. It is possible that both the intensity of the RPE anchor and the duration of work bout itself could affect an individual's ability to accurately and reliably regulate their exercise intensity or work rate to the desired target. This study aimed to assess the reliability and reproducibility of self-paced submaximal exercise of different intensities in trained competitive cyclists using long, medium, and short workload periods.

METHODOLOGY

Participants. Twenty well-trained cyclists (18 males, 2 females; mean ± SD: age 38 ± 11 years, height 176.6 ± 9.7 cm, mass 72.4 ± 9.2 kg, $\dot{V}O_{2max}$ 55.07 ± 11.06 $mL.kg^{-1}.min^{-1}$, maximum minute power (MMP) 337 ± 54 W, HR_{max} 180 ± 9 bpm), with at least 3 years of cycling training and racing experience (Performance Level 3-4 [11,37]), provided written informed consent to voluntarily participate in the study which held full ethical approval from the local institutional ethics committee according to the Declaration of Helsinki.

Study Design

Participants visited the exercise testing laboratory on four separate occasions in a euhydrated state over a period of 5 ± 2 weeks, with visits separated by at least 72 hours to ensure full recovery between each. In Visit 1, participants completed an incremental exercise test to identify $\dot{V}O_{2max}$ and MMP, followed by a $\dot{V}O_{2max}$ confirmation effort (see: *Maximal incremental test*) and familiarisation with laboratory equipment. Visits 2 to 4 comprised of 3 supervised exercise sessions each consisting of 3 separate self-paced exercise bouts; 3 RPE-anchored exercise intensities (RPE 9, 13, 17) lasting either 1, 4, or 8 minutes completed in a randomized order during each visit (see *Exercise testing sessions*). All visits for each participant were completed within the same 3-hour period of the day and participants were asked to maintain a consistent diet and lifestyle, and to avoid alcohol and strenuous exercise the day before the sessions. To aid familiarisation, participants were asked to incorporate effort-based training bouts similar to those included in the present investigation into their training before commencing the study. In addition, participants had previous experience of exercise testing and the use of the RPE scale, but not specifically in "*production mode*". A cooling fan present and plain water available for participants to drink ad libitum.

Maximal incremental test. Participants completed a maximal incremental test on a bicycle ergometer (Cyclus2, RBM Electronics, Leipzig, Germany) to identify MMP, $\dot{V}O_{2max}$, and maximum heart rate (HR_{max}). After riding at 100W for a period of 10 minutes, the external load was increased by 20W every 60 seconds until volitional exhaustion, defined as the point where self-selected cadence dropped below 60rpm despite strong verbal encouragement [23]. MMP was calculated as the highest power output averaged over a period of 60 seconds, $\dot{V}O_{2max}$ was calculated as the highest $\dot{V}O_2$ achieved over a period of 30 seconds, and HR_{max} was identified as the highest

HR value reached in the incremental test. After a period of 30 minutes (10 minutes cool-down at 100W, 10 minutes seated rest, and 10 minutes warm-up at 100W) participants were instructed to exercise at MMP until volitional exhaustion in order to identify time-to-exhaustion (TTE) at an intensity corresponding to $\dot{V}O_{2max}$ and also to confirm $\dot{V}O_{2max}$ values recorded during the incremental test.

Exercise testing sessions. After a warm-up period of 10 minutes easy cycling, participants completed randomised work bouts of either 1-min, 4-min, and 8-min (SHORT, MED, LONG) at RPEs of either 9, 13, 17 (6 – 20 scale [4]), with 5 minutes easy cycling between each bout. Participants were instructed to self-select their cycling power output in order to achieve and maintain the desired RPE anchor for each bout by using their gearing system on their bicycle. Elapsed time was available for participants during all bouts, but they were blind to all other data and information, and no encouragement was given during exercise to minimize effects of external factors [10]. Power output was continuously measured, and heart rate was transmitted using a compatible heart rate strap (Cyclus2 heart rate, RBM Electronics, Leipzig, Germany). Data was subsequently segmented into the 9 sections corresponding to the 9 exercise bouts for analysis. Respiratory gas exchange data were measured continuously throughout all sessions using an online gas analyser (Metalyzer 3B, CORTEX Biophysik GmbH, Leipzig, Germany), and an appropriately sized facemask covering the nose and mouth. A 10-second rolling average was used when analysing respiratory gas exchange data. Expired gas data were analysed to quantify volume of expired oxygen ($\dot{V}O_2$), volume of expired carbon dioxide ($\dot{V}CO_2$), and minute ventilation ($\dot{V}_E$). Muscle oxygenation was measured using spatially resolved dual-wavelength near-infrared spectroscopy (NIRS; Portamon, Artinis Medical Systems, BV, Netherlands), with the optode positioned 10cm superior to the lateral epicondyle of the femur at the distal end of the vastus lateralis muscle and secured with muscle tape and bandage. NIRS data were analysed relative to a 2-min resting baseline measurement completed prior to each testing session, to provide relative change (Δ) in tissue saturation index (TSI%), oxy-haemoglobin (O_2Hb), and deoxyhaemoglobin (HHb). Prior to each exercise session, the Daily Analysis of Life Demands for Athletes (DALDA [8]) questionnaire was administered and following the session the Task Load Index (NASA-TLX [20]) was administered.

Data and statistical analysis

Data were processed according to the combination of exercise duration (SHORT, MED, and LONG), intensity (RPE 9, 13, 17), and session repeat (3 x SHORT, MED, and LONG). Prior to statistical analysis all data was checked for normality of distribution. Sphericity of the data was investigated using the Mauchley test, and the Greenhouse-Geisser adjustment was made when data was deemed non-spherical. Data are reported as mean and standard deviation (mean ± SD), and CV's are presented as a percentage unless specified otherwise. When assessing variability, low CV's indicating a consistent response, and high CV's displaying variable response.

Repeated measures analysis of variance (ANOVA) was used to analyse power output and physiological response data between exercise session visits, and two-way repeated-measures ANOVA (duration x intensity) was used to analyse performance and physiological parameters. When significant differences were found, Bonferroni test was used to determine where differences occurred. Effect sizes were calculated using partial eta squared (η_p^2) and were defined as small, medium, or large based upon 0.10, 0.25, and above 0.40, respectively [7].

Linear mixed modelling was completed to analyse the variability in power output, work done, HR, %MMP, $\%HR_{max}$, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, $\%\dot{V}O_{2max}$, TSI%, O_2Hb, and HHb for each combination of duration and intensity. Quantification of individual variation observed was completed by calculating CV's for the within- (WAV), between- (BAV), and total variability (TV) of each parameter by expressing the standard deviation relative to the mean for each parameter. Linear mixed models, ANOVA's, and post-hoc testing were conducted using the Statistical Package for the Social Sciences, version 26 for Mac OS X (SPSS, IBM®, Armonk, New York, USA), and an alpha level was set at P < .05 for the criteria for detection of significance in all cases. CV was calculated in Microsoft Excel (Excel v16.3 Microsoft, Redmond, Washington, USA).

RESULTS

Power output and cardiovascular response during exercise bouts

Power, heart rate, and work done are reported in Table 1, and power as %MMP and HR as $\%HR_{max}$ in Table 2. Increases in power ($F_{(1.517, 89.53)} = 596.297$; $\eta_p^2 = 910$), HR ($F_{(1.539, 90.829)} = 681.286$; $\eta_p^2 = .920$), work done ($F_{(1.467, 86.553)} = 633.586$; $\eta_p^2 = .915$), %MMP ($F_{(1,59)} = 919.212$; $\eta_p^2 = .940$), and $\%HR_{max}$ ($F_{(1.578, 93.095)} = 709.357$; $\eta_p^2 = .923$) were found as RPE anchor increased ($P < .001$). Changes in power ($F_{(1.301, 76.771)} = 71.292$; $\eta_p^2 = .547$), HR ($F_{(2, 118)} = 282.581$; $\eta_p^2 = 827$), work done ($F_{(1.045, 61.678)} = 1309.505$; $\eta_p^2 = 957$), %MMP ($F_{(1.414, 83.444)} =$

22.101; η_p^2 = .273), and % HR_{max} ($F_{(2, 118)}$ = 270.719; η_p^2 = 821) were found as time increased (P < .001). An interaction effect of time and RPE anchor was observed for power ($F_{(2.562, 151.172)}$ = 51.178; η_p^2 = .465), HR ($F_{(2.816, 166.160)}$ = 29.766; η_p^2 = .335), work done ($F_{(2.383, 140.613)}$ = 314.413; η_p^2 = .842), %MMP ($F_{(1.829, 107.922)}$ = 14.640; η_p^2 = .199), and HR as %HR_{max} ($F_{(2.773, 163.623)}$ = 29.634; η_p^2 = .334)(P < .001). Overall, TV, BAV, and WAV in power and work done decreased as intensity and duration increased. Power TV was lowest in LONG bouts of RPE 17, and highest in SHORT bouts of RPE 9. Heart rate displayed lower CV's in comparison to power and work done, with greater consistency being displayed as exercise intensity increased. TV, BAV, and WAV were all higher when reporting %MMP compared to %HRmax, with higher levels of consistency being found as intensity and duration increases.

INSERT TABLE 1 HERE

INSERT TABLE 2 HERE

Expired gas response during exercise bouts

$\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}_E$ are reported in Table 3, and %$\dot{V}O_{2max}$ in Table 2. Increases in $\dot{V}O_2$ ($F_{(1.473, 86.936)}$ = 529.082; η_p^2 = .90), $\dot{V}CO_2$ ($F_{(1.485, 87.629)}$ = 494.818; η_p^2 = .893), $\dot{V}_E$ ($F_{(1.507, 88.896)}$ = 371.169; η_p^2 = .863), %$\dot{V}O_{2max}$ ($F_{(1.676, 98.908)}$ = 684.862; η_p^2 = .921) were found as RPE anchor increased (P < .001). Changes in $\dot{V}O_2$ ($F_{(1.728, 101.944)}$ = 228.521; η_p^2 = .795), $\dot{V}CO_2$ ($F_{(1.723, 101.629)}$ = 203.813; η_p^2 = .776), $\dot{V}_E$ ($F_{(1.796, 105.985)}$ = 158.104; η_p^2 = .728), %$\dot{V}O_{2max}$ ($F_{(1.738, 102.55)}$ = 194.221; η_p^2 = .767) were found as time increased (P < .001). An interaction effect of time and duration was observed for $\dot{V}O_2$ ($F_{(3.177, 187.454)}$ = 39.009; η_p^2 = .398), $\dot{V}CO_2$ ($F_{(3.11, 183.511)}$ = 36.972; η_p^2 = .385), $\dot{V}_E$ ($F_{(2.914, 171.899)}$ = 43.228; η_p^2 = .423), %$\dot{V}O_{2max}$ ($F_{(3.448, 203.438)}$ = 32.817; η_p^2 = .357)(P < .001). Overall, TV, BAV, and WAV in $\dot{V}O_2$, $\dot{V}CO_2$, and %$\dot{V}O_{2max}$ decreased as intensity and duration increased. Variability in $\dot{V}_E$ was similar across intensities and durations. Total CV in $\dot{V}O_2$ was lowest in LONG bouts of RPE 17, and highest in LONG bouts of RPE 9.

INSERT TABLE 3 HERE

Muscle oxygenation response during exercise bouts

ΔTSI%, ΔO*2*Hb, and ΔHHb are reported in Table 4. Decreases in ΔTSI% ($F_{(1.245, 23.660)}$ = 65.598; η_p^2 = .775), ΔO_2Hb ($F_{(1.147, 21.791)}$ = 61.594; η_p^2 = .764), and increases in ΔHHb ($F_{(1.056, 20.073)}$ = 27.735; η_p^2 = .593) were found as RPE anchor increased (P < .001). Decreases in ΔTSI% ($F_{(1.503, 28.561)}$ =

11.798; η_p^2 = .383) and increases in ΔHHb ($F_{(1.223, 23.233)}$ = 13.385; η_p^2 = .413) were found as time increased (*P* < .001). No change was observed in ΔO_2Hb ($F_{(1.468, 27.901)}$ = .918; η_p^2 = .046, *P* = 383) as time increased. No interaction effects were observed for ΔTSI% ($F_{(4, 76)}$ = .695; η_p^2 = .035, *P* = 598), ΔO_2Hb ($F_{(4, 76)}$ = .988; η_p^2 = .049, *P* = 420), or ΔHHb ($F_{(2.538, 48.223)}$ = 1.115; η_p^2 = .055, *P* = 346). Overall, TV, WAV, and BAV in ΔTSI%, ΔO_2Hb, and ΔHHb increased as effort level and duration increased. Total CV in ΔHHb was lowest in SHORT bouts of RPE 17, and highest in MED bouts of RPE 9.

INSERT TABLE 4 HERE

Psychological response comparisons

No differences were observed for perceived levels of stress prior to sessions (*P* = .765, η_p^2 = .008) and load attributed to mental (*P* = .338, η_p^2 = .048), physical (*P* = .576, η_p^2 = .025), temporal (*P* = .257, η_p^2 = .06), performance (*P* = .748, η_p^2 = .013), effort (*P* = .569, η_p^2 = .025), and frustration (*P* = .860, η_p^2 = .007) sources following each testing session.

Session order differences

All data for repeated sessions were not significantly different for RPE9 ($P \geq .098$, $\eta_p^2 \leq .115$), RPE13 ($P \geq .109$, $\eta_p^2 \leq .11$), and RPE17 ($P \geq .056$, $\eta_p^2 \leq .154$), with the exception of both $\dot{V}CO_2$ (*P* = .045, η_p^2 = .18) and $\dot{V}_E$ (*P* = .026, η_p^2 = .168) which were higher in repeat 2 versus repeat 1 in SHORT_RPE17.

DISCUSSION

The present study aimed to investigate both the physiological response, and consistency of response, during self-paced submaximal exercise over different intensities and durations in trained competitive cyclists. The main findings of this study were that there were interactions between intensity and duration across all measured variables with the exception of muscle oxygenation measures. Specifically, increases in intensity and duration resulted in greater consistency within measured parameters.

Unsurprisingly, as demonstrated in other research, increasing the RPE anchor resulted in higher cycling power outputs and greater physiological responses [4,21]. Moreover, when duration increased, power output remained similar during RPE 9 bouts, but decreased during RPE 13 and 17 bouts, suggesting that participants altered their power output in order to maintain the same perception of effort as the duration of the bout is extended [45]. The interaction between duration and intensity is also shown by changes difference in work done during each bout, as this is influenced by both duration and intensity.

As shown by Table 1, the current study found lower levels of variability during exercise at higher RPE anchors. When exercising at higher absolute exercise intensity, a small change in power output can result in large changes in physiological response and fatigue compared to lower absolute exercise intensities [67], thus participants are likely to control their exercise intensity within a closer bandwidth, highlighted by the ranges of WAV observed at RPE 9, 13, and 17 (13.1-19.7%, 9.4%-15.2%, and 5.3%-10.6%, respectively). This finding is supported by previous work demonstrating lower variability in measured physiological variables at higher exercise intensity, with lowest variation during maximal conditions [2]. It is likely that as the intensity of exercise increases, the cyclist will likely commit more conscious attention towards the required work rate and physiological responses, such as regionalised pain and pulmonary ventilation [44]. Indeed, as RPE anchor and duration increased, the WAV observed in HR, $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}_E$ decreased (HR, 5.3% to 3.0%; $\dot{V}O_2$, 14.8% to 4.3%; $\dot{V}CO_2$, 10.9% to 5.9%; and $\dot{V}_E$, 10.8% to 7.0%), indicating greater homogeneity in the workloads produced by the athletes at a given RPE. The heightened perception of changes in the aforementioned physiological parameters may result in a shift in the cyclist's attention towards internal-associative modes at the higher intensities and durations, and away from external-dissociative mode experienced at lower intensities [44]. This is a possible explanation for the reduced variability in power output, and therefore physiological responses, as intensity and duration increased. However, in contrast to the findings of the current study, some research has suggested that when athletes are instructed to perform maximal effort time trials, reliability of performance is high, but may decline as duration is increased [41]. The apparent reasons for these conflicting findings are unclear but could be related to fatigue over the longer duration efforts involved, as well as methodological in nature as participants were instructed to "*as fast as possible*" and therefore may have resulted in differing pacing profiles to the present study [41].

Changes in skeletal muscle oxygenation follow expected patterns of decreasing ΔTSI% ΔO_2Hb and increasing ΔHHb with the increase of exercise intensity [25,27,32,47(p)]. Duration could be seen to impact skeletal muscle oxygenation less than intensity, with differences only being found for ΔTSI% and

ΔHHb during SHORT bouts, likely due to inadequate time for steady state skeletal muscle oxygenation consumption to be attained before the end of the exercise bout, compared to MED or LONG [33,40]. Interestingly, ΔO_2Hb did not differ in this manner, displaying similar levels across all durations for each RPE anchor. NIRS data displayed large levels of both WAV and BAV, particularly ΔTSI% (a range of -83.8% to 3.3%, respectively) and ΔO_2Hb (-231.1% to 422.7%), with ΔHHb presenting lower levels of variability in most cases (18.1% to 44.4%). The levels of WAV observed in ΔTSI%, ΔO_2Hb, and ΔHHb were not affected by changes in intensity or duration, although BAV reduced with increased intensity (Table 4). This finding is somewhat in contrast to previous research which has shown increased reliability of skeletal muscle oxygenation measurements at higher versus lower work rate [19], suggesting that blood volume and blood flow may be more variable at lower intensities due to the reduced physiological demand on the working muscle.

Maximal time trials have been observed to have higher reliability compared to any of the durations or intensities investigated in the current study [12,13,28,46,48]. WAV observed from 4-min efforts in the current study display increasing reliability as intensity increases; 15.4% (RPE 9), 10.8% (RPE 13), and 8.6% (RPE 17), which shows agreement with lower CV's displayed from maximal 4-min TT's; 2.2% [28] and 2.0% [13]. Longer maximal efforts similarly display higher levels of reliability compared to shorter efforts; 20min TT 1.4% [28], 20min TT 1.3% [12], 16.1km TT 2.7% [46], 20km TT 2.7% [48]. Similarly, in the present study, increased levels of reliability were observed during 8min efforts; 19.7% (RPE 9), 9.4% (RPE 13), and 5.3% (RPE 17). The above suggests that the adoption of intensity prescriptions of a high or maximal self-paced intensity and longer duration intervals in a training session format could provide a novel opportunity to homogenise the exercise prescription. The higher the self-paced exercise intensity, the more consistent the power output distribution and physiological response on a single-bout basis. The intensity prescription of maximal session effort, which is the maintenance of high levels of physical exertion over a duration that would result in a maximal exertion for a given training session has been utilised in research [1,45], but not with the goal of assessing individual variability in exercise training response.

Previous research has demonstrated a difference in perceptual response to exercise between trained and untrained individuals [22], suggesting competitive athletes are more able to accurately and reliably utilise RPE to regulate exercise intensity. It has been previously suggested that perceptual responses (in this case, session RPE) are more accurate when the athlete has more experience [3]. Experience athletes are better equipped to perceive effort accurately and reliably as they will regularly experience the use of perception of effort [18]. Future research may look to investigate the differences in the changes in reliability between trained and untrained individuals as intensity and duration are manipulated. However, based on the findings in the current study, the utilisation of effort-based prescriptions to elicit a reliable exercise stimulus may be limited to high or maximal session effort prescriptions, and therefore limit the application to lower intensity training. Nevertheless, this training methodology could hold potential for decreasing levels of individual variability in response to high intensity training.

PRACTICAL APPLICATIONS

Our findings could be utilised by athletes and coaches to potentially reduce individual variability in exercise training response by including effort-based training of high intensity and longer durations. Coaches may also be able to detect changes in the performance of an athlete when using regular maximal effort-based exercise bouts and detecting when power output exceeds the expected WAV.

CONCLUSION

In conclusion, the present study demonstrates that using self-paced exercise intensity prescriptions at higher effort levels and longer durations result in greatest consistency on both a within-athlete and between-athlete basis. This presents a direction to investigate the use of maximal effort prescriptions for whole training sessions in order to provide greater consistency of training stimulus, and potentially greater consistency in long-term training response.

ACKNOWLEDGMENTS

None.

REFERENCES

1. Abbiss CR, Peiffer JJ, Meeusen R, Skorski S. Role of Ratings of Perceived Exertion during Self-Paced Exercise: What are We Actually Measuring? *Sports Medicine*. 2015;45(9):1235-1243. doi:10.1007/s40279-015-0344-5

2. Bagger M, Petersen PH, Pedersen PK. Biological Variation in Variables Associated with Exercise Training. *International Journal of Sports Medicine*. 2003;24(6):433-440. doi:10.1055/s-2003-41180

3. Barroso R, Cardoso RK, Carmo EC, Tricoli V. Perceived Exertion in Coaches and Young Swimmers With Different Training Experience. *International Journal of Sports Physiology and Performance*. 2014;9(2):212-216. doi:10.1123/ijspp.2012-0356

4. Borg. *Borg's Perceived Exertion and Pain Scales*. Human Kinetics; 1998.

5. Buckley JP. Ratings of perceived exertion in braille: validity and reliability in production mode. *British Journal of Sports Medicine*. 2000;34(4):297-302. doi:10.1136/bjsm.34.4.297

6. Burnley M, Jones AM. Power–duration relationship: Physiology, fatigue, and the limits of human performance. *European Journal of Sport Science*. 2018;18(1):1-12. doi:10.1080/17461391.2016.1249524

7. Cohen J. Statistical Power Analysis. *Current Directions in Psychological Science*. 1992;1(3):98-101.

8. Coutts AJ, Slattery KM, Wallace LK. Practical tests for monitoring performance, fatigue and recovery in triathletes. *Journal of Science and Medicine in Sport*. 2007;10(6):372-381. doi:10.1016/j.jsams.2007.02.007

9. Coyle EF, Coggan AR, Hopper MK, Walters TJ. Determinants of endurance in well-trained cyclists. *Journal of Applied Physiology*. 1988;64(6):2622-2630. doi:10.1152/jappl.1988.64.6.2622

10. Currell K, Jeukendrup AE. Validity, Reliability and Sensitivity of Measures of Sporting Performance: *Sports Medicine*. 2008;38(4):297-316. doi:10.2165/00007256-200838040-00003

11. Decroix L, De Pauw K, Foster C, Meeusen R. Guidelines to Classify Female Subject Groups in Sport-Science Research. *International Journal of Sports Physiology and Performance*. 2016;11(2):204-213. doi:10.1123/ijspp.2015-0153

12. Driller MW. The reliability of a 30-minute performance test on a Lode cycle ergometer. 2012;1:7.

13. Driller MW, Argus CK, Bartram JC, et al. Reliability of a 2-Bout Exercise Test on a Wattbike Cycle Ergometer. *International Journal of Sports Physiology and Performance*. 2014;9(2):340-345. doi:10.1123/ijspp.2013-0103

14. Ekblom B, Golobarg AN. The Influence of Physical Training and Other Factors on the Subjective Rating of Perceived Exertion. *Acta Physiologica Scandinavica*. 1971;83(3):399-406. doi:10.1111/j.1748-1716.1971.tb05093.x

15. Eston R. Use of Ratings of Perceived Exertion in Sports. *International Journal of Sports Physiology and Performance*. 2012;7(2):175-182. doi:10.1123/ijspp.7.2.175

16. Eston RG, Faulkner JA, Mason EA, Parfitt G. The validity of predicting maximal oxygen uptake from perceptually regulated graded exercise tests of different durations. *European Journal of Applied Physiology*. 2006;97(5):535-541. doi:10.1007/s00421-006-0213-x

17. Eston RG, Parfitt G, Campbell L, Lamb KL. Reliability of Effort Perception for Regulating Exercise Intensity in Children Using the Cart and Load Effort Rating (CALER) Scale. *Pediatric Exercise Science*. 2000;12(4):388-397. doi:10.1123/pes.12.4.388

18. Gearhart RF. Comparison of memory and combined exercise and memory-anchoring procedures on ratings of perceived exertion during short duration, near-peak-intensity cycle ergometer exercise. *Perceptual and Motor Skills*. 2004;99(3):775-784.

19. Gerz E, Geraskin D, Franke J, Platen P, Steimers A, Kohl-Bareis M. Tissue Oxygenation During Exercise Measured with NIRS: Reproducibility and Influence of Wavelengths. In: Van Huffel S, Naulaers G, Caicedo A, Bruley DF, Harrison DK, eds. *Oxygen Transport to Tissue XXXV*. Vol 789. Springer New York; 2013:171-177. doi:10.1007/978-1-4614-7411-1_24

20. Hart SG, Staveland LE. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In: *Advances in Psychology*. Vol 52. Elsevier; 1988:139-183. doi:10.1016/S0166-4115(08)62386-9

21. Hartshorn J, Lamb K. The Reproducibility of Perceptually Regulated Exercise Responses During Short-Term Cycle

Ergometry. *International Journal of Sports Medicine*. 2004;25(5):362-367. doi:10.1055/s-2004-815840

22. Hassmén P. Perceptual and physiological responses to cycling and running in groups of trained and untrained subjects. *Europ J Appl Physiol*. 1990;60(6):445-451. doi:10.1007/BF00705035

23. Hopker JG, O'Grady C, Pageaux B. Prolonged constant load cycling exercise is associated with reduced gross efficiency and increased muscle oxygen uptake. *Scandinavian Journal of Medicine & Science in Sports*. 2017;27(4):408-417. doi:10.1111/sms.12673

24. Hurley BF, Hagberg JM, Allen WK, et al. Effect of training on blood lactate levels during submaximal exercise. *Journal of Applied Physiology*. 1984;56(5):1260-1264. doi:10.1152/jappl.1984.56.5.1260

25. Jones B, Hesford CM, Cooper CE. The Use of Portable NIRS to Measure Muscle Oxygenation and Haemodynamics During a Repeated Sprint Running Test. In: Van Huffel S, Naulaers G, Caicedo A, Bruley DF, Harrison DK, eds. *Oxygen Transport to Tissue XXXV*. Vol 789. Springer New York; 2013:185-191. doi:10.1007/978-1-4614-7411-1_26

26. Katch V, Weltman A, Sady S, Freedson P. Validity of the relative percent concept for equating training intensity. *European Journal of Applied Physiology and Occupational Physiology*. 1978;39(4):219-227. doi:10.1007/BF00421445

27. Kemps HMC, Prompers JJ, Wessels B, et al. Skeletal muscle metabolic recovery following submaximal exercise in chronic heart failure is limited more by O2 delivery than O2 utilization. *Clinical Science*. 2009;118(3):203-210. doi:10.1042/CS20090220

28. MacInnis MJ, Thomas ACQ, Phillips SM. The Reliability of 4-Minute and 20-Minute Time Trials and Their Relationships to Functional Threshold Power in Trained Cyclists. *International Journal of Sports Physiology and Performance*. 2019;14(1):38-45. doi:10.1123/ijspp.2018-0100

29. Mann T, Lamberts RP, Lambert MI. Methods of Prescribing Relative Exercise Intensity: Physiological and Practical Considerations. *Sports Medicine*. 2013;43(7):613-625. doi:10.1007/s40279-013-0045-x

30. Mayes R, Hardman A, Williams C. The influence of training on endurance and blood lactate concentration during submaximal exercise. *British Journal of Sports Medicine*. 1987;21(3):119-124.

31. Myles WS, Maclean D. A comparison of response and production protocols for assessing perceived exertion. *European Journal of Applied Physiology and Occupational Physiology*. 1986;55(6):585-587. doi:10.1007/BF00423201

32. Niemeijer VM, Spee RF, Jansen JP, et al. Test-retest reliability of skeletal muscle oxygenation measurements during submaximal cycling exercise in patients with chronic heart failure. *Clin Physiol Funct Imaging*. 2017;37(1):68-78. doi:10.1111/cpf.12269

33. Nioka S, Moser D, Lech G, et al. Muscle Deoxygenation in Aerobic and Anaerobic Exercise. In: Hudetz AG, Bruley DF, eds. *Oxygen Transport to Tissue XX*. Vol 454. Springer US; 1998:63-70. doi:10.1007/978-1-4615-4863-8_8

34. Noble BJ, Robertson RJ. *Perceived Exertion*. Human Kinetics; 1996.

35. Okuno NM, Soares-Caldeira LF, Milanez VF, Perandini LAB. Predicting time to exhaustion during high-intensity exercise using rating of perceived exertion. *Science & Sports*. 2015;30(6):e155-e161. doi:10.1016/j.scispo.2015.05.003

36. Parfitt G, Evans H, Eston R. Perceptually Regulated Training at RPE13 Is Pleasant and Improves Physical Health: *Medicine & Science in Sports & Exercise*. 2012;44(8):1613-1618. doi:10.1249/MSS.0b013e31824d266e

37. de Pauw KD, Roelands B, Cheung SS, de Geus B, Rietjens G, Meeusen R. Guidelines to Classify Subject Groups in Sport-Science Research. *International Journal of Sports Physiology and Performance*. 2013;8(2):111-122. doi:10.1123/ijspp.8.2.111

38. Poole DC, Gaesser GA. Response of ventilatory and lactate thresholds to continuous and interval training. *Journal of Applied Physiology*. 1985;58(4):1115-1121. doi:10.1152/jappl.1985.58.4.1115

39. Robertson RJ, Falkel JE, Drash AL, et al. Effect of blood pH on peripheral and central signals of perceived exertion.

Medicine and Science in Sports and Exercise. 1986;18(1):114-122.

40. Saltin B, Radegran G, Koskolou MD, Roach RC. Skeletal muscle blood flow in humans and its regulation during exercise. *Acta Physiol Scand*. 1998;162(3):421-436. doi:10.1046/j.1365-201X.1998.0293e.x

41. Schabort EJ, Hawley JA, Hopkins WG, Mujika I, Noakes TD. A new reliable laboratory test of endurance performance for road cyclists. *Med Sci Sports Exerc*. 1998;30:1744-1750.

42. Scharhag-Rosenberger F, Meyer T, Gäßler N, Faude O, Kindermann W. Exercise at given percentages of VO2max: Heterogeneous metabolic responses between individuals. *Journal of Science and Medicine in Sport*. 2010;13(1):74-79. doi:10.1016/j.jsams.2008.12.626

43. Scherr J, Wolfarth B, Christle JW, Pressler A, Wagenpfeil S, Halle M. Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *European Journal of Applied Physiology*. 2013;113(1):147-155. doi:10.1007/s00421-012-2421-x

44. Schomer H. Mental strategies and the perception of effort of marathon runners. *International Journal of Sport Psychology*. 1986;17(1):41-59.

45. Seiler S, Sylta Ø. How Does Interval-Training Prescription Affect Physiological and Perceptual Responses? *International Journal of Sports Physiology and Performance*. 2017;12(s2):S2-80-S2-86. doi:10.1123/ijspp.2016-0464

46. Sparks A, Williams E, Jones H, Bridge C, Marchant D. Test-retest reliability of a 16.1 km time trial in trained cyclists using the CompuTrainer ergometer. . *Test*. 2016;5:7.

47. Sperandio PA, Borghi-Silva A, Barroco A, Nery LE, Almeida DR, Neder JA. Microvascular oxygen delivery-to-utilization mismatch at the onset of heavy-intensity exercise in optimally treated patients with CHF. *American Journal of Physiology-Heart and Circulatory Physiology*. 2009;297(5):H1720-H1728. doi:10.1152/ajpheart.00596.2009

48. Sporer B, McKenzie D. Reproducibility of a Laboratory Based 20-km Time Trial Evaluation in Competitive Cyclists Using the Velotron Pro Ergometer. *International*

Journal of Sports Medicine. 2007;28(11):940-944. doi:10.1055/s-2007-964977

49. St Clair Gibson A, Lambert EV, Rauch LHG, et al. The Role of Information Processing Between the Brain and Peripheral Physiological Systems in Pacing and Perception of Effort. *Sports Medicine*. 2006;36(8):705-722. doi:10.2165/00007256-200636080-00006

50. Thompson J, Lamb KL. The effect of perceptual anchoring on the reliability of exercise regulation in young children. *J Sports Sci*. 2001;19:27-28.

51. Weltman A, Snead D, Seip R, et al. Percentages of Maximal Heart Rate, Heart Rate Reserve and $\dot{V}O_2$ max for Determining Endurance Training Intensity in Male Runners. *International Journal of Sports Medicine*. 1990;11(03):218-222. doi:10.1055/s-2007-1024795

52. Weltman A, Weltman J, Rutt R, et al. Percentages of Maximal Heart Rate, Heart Rate Reserve, and $\dot{V}O_2$ peak for Determining Endurance Training Intensity in Sedentary Women*. *International Journal of Sports Medicine*. 1989;10(03):212-216. doi:10.1055/s-2007-1024903

Table 1 - Power output and cardiovascular response during RPE-clamped exercise bouts showing mean data, standard deviation, and coefficients of variation.

Variable				Mean	SD	Coefficient of variation TV (%)	BAV (%)	WAV (%)
Power output (W)								
RPE 9	*a*	SHORT		95	41	43.1	43.5	13.1
		MED		93	40	42.8	43.3	15.4
		LONG		96	39	41.0	41.3	19.7
RPE 13	*a*	SHORT	*b*	228	69	30.3	30.5	15.2
		MED		200	49	24.6	24.9	10.8
		LONG		202	48	23.9	24.2	9.4
RPE 17	*a*	SHORT	*b*	349	97	27.7	8.9	10.6
		MED	*b*	275	61	22.1	22.4	8.6
		LONG	*b*	261	50	19.3	19.5	5.3
Work done (kJ)								
RPE 9	*a*	SHORT	*b*	6	2	44.0	44.4	11.8
		MED	*b*	22	10	43.1	43.6	16.1
		LONG	*b*	46	19	40.8	41.2	19.7
RPE 13	*a*	SHORT	*b*	14	4	30.7	30.9	15.5
		MED	*b*	48	12	24.7	25.0	10.7
		LONG	*b*	97	23	23.9	24.3	9.3
RPE 17	*a*	SHORT	*b*	21	6	27.4	8.6	11.1
		MED	*b*	66	15	22.2	22.5	8.5
		LONG	*b*	125	24	19.2	19.5	5.2
Heart rate (bpm)								
RPE 9	*a*	SHORT		109	12	11.3	11.5	5.3
		MED		111	15	13.8	14.0	7.5
		LONG		111	16	14.6	14.7	6.5
RPE 13	*a*	SHORT	*b*	127	14	10.9	11.0	6.1
		MED	*c*	138	13	9.7	9.9	6.6
		LONG		142	15	10.3	10.5	6.1
RPE 17	*a*	SHORT	*b*	139	12	8.5	3.0	3.4
		MED	*b*	154	12	8.0	8.1	4.2
		LONG	*b*	160	11	6.7	6.8	3.0

a = Significant difference observed between all RPE's ($P < .001$). b = $P < .001$ vs. all other durations. c = $P < .05$ vs. LONG.

Table 2 - Relative power output, cardiovascular, and expired gas response during RPE-clamped exercise bouts showing mean data, standard deviation, and coefficients of variation.

Variable				Mean	SD	Coefficient of variation		
						TV (%)	BAV (%)	WAV (%)
Power as % MMP (%)								
RPE 9	*a*	SHORT		28	11	39.2	39.6	13.5
		MED		28	11	40.5	41.1	15.6
		LONG		29	11	39.5	39.9	19.6
RPE 13	*a*	SHORT		67	17	24.7	25.0	15.2
		MED		59	12	19.4	19.7	10.8
		LONG		60	11	17.6	17.9	9.4
RPE 17	*a*	SHORT	*b*	103	20	19.8	6.5	10.6
		MED	*b*	81	9	11.7	11.8	8.6
		LONG	*b*	77	6	7.8	7.5	5.2
Heart rate as % HR_{max} (%)								
RPE 9	*a*	SHORT		60	6	10.6	10.8	5.5
		MED		62	8	13.6	13.8	7.6
		LONG		61	9	14.2	14.3	6.4
RPE 13	*A*	SHORT	*b*	70	7	10.1	10.2	6.0
		MED	*c*	77	7	9.6	9.7	6.4
		LONG		79	8	10.0	10.1	6.1
RPE 17	*a*	SHORT	*b*	77	6	7.3	2.5	3.3
		MED	*b*	85	6	6.7	6.8	4.2
		LONG	*b*	89	4	5.0	5.0	2.9
$\dot{V}O_2$ as % $\dot{V}O_{2max}$ (%)								
RPE 9	*a*	SHORT		38.6	8.3	21.5	21.7	10.0
		MED		39.4	9.9	25.2	25.6	10.7
		LONG		40.6	10.1	24.8	25.1	13.0
RPE 13	*a*	SHORT	*b*	56.7	10.5	18.5	18.6	12.0
		MED	*c*	65.2	11.5	17.6	17.3	9.7
		LONG		69.2	11.9	17.2	17.2	8.6
RPE 17	*a*	SHORT	*b*	67.7	11.0	16.2	5.0	10.3
		MED	*b*	82.2	10.8	13.1	13.2	7.6
		LONG	*b*	86.3	11.4	13.3	13.4	4.2

a = Significant difference observed between all RPE's ($P < .001$). b = $P < .001$ vs. all other durations. c = $P < .05$ vs. LONG.

Table 3 - Expired gas response during RPE-clamped exercise bouts showing mean data, standard deviation, and coefficients of variation.

							Coefficient of variation		
Variable					**Mean**	**SD**	**TV (%)**	**BAV (%)**	**WAV (%)**
$\dot{V}O_2$ (L.min^{-1})									
	RPE 9	*a*	SHORT	*c*	1.50	0.38	25.3	24.8	14.8
			MED		1.51	0.39	26.1	26.3	10.4
			LONG		1.53	0.43	27.9	28.3	11.2
	RPE 13	*a*	SHORT	*b*	2.21	0.52	23.7	23.7	12.2
			MED	*c*	2.54	0.53	20.9	20.9	9.6
			LONG		2.69	0.54	20.0	20.2	8.5
	RPE 17	*a*	SHORT	*b*	2.65	0.61	22.9	8.3	10.2
			MED	*b*	3.22	0.63	19.6	19.8	7.6
			LONG	*b*	3.36	0.57	16.9	17.1	4.3
$\dot{V}CO_2$ (L.min^{-1})									
	RPE 9	*a*	SHORT		1.39	0.38	27.1	27.2	10.9
			MED		1.42	0.41	28.7	29.1	10.8
			LONG		1.48	0.44	29.9	30.3	15.0
	RPE 13	*a*	SHORT	*b*	2.08	0.55	26.6	26.6	14.5
			MED	*c*	2.51	0.65	25.8	25.6	12.4
			LONG		2.73	0.61	22.5	22.5	11.0
	RPE 17	*a*	SHORT	*b*	2.75	0.84	30.7	10.5	15.9
			MED		3.62	0.82	22.8	23.0	11.1
			LONG		3.67	0.67	18.2	18.4	5.9
$\dot{V}_E$ (L.min^{-1})									
	RPE 9	*a*	SHORT		42.17	11.16	26.5	26.4	10.8
			MED		42.33	12.18	28.8	29.2	12.4
			LONG		42.94	10.99	25.6	25.8	13.3
	RPE 13	*a*	SHORT	*b*	61.49	17.94	29.2	29.2	15.2
			MED	*c*	72.32	20.18	27.9	28.0	14.5
			LONG		77.53	20.68	26.7	27.0	11.6
	RPE 17	*a*	SHORT	*b*	81.50	25.37	31.1	11.0	14.4
			MED	*b*	104.20	27.71	26.6	27.0	10.6
			LONG	*b*	111.77	24.20	21.7	22.0	7.0

a = Significant difference observed between all RPE's ($P < .001$). b = $P < .001$ vs. all other durations. c = $P < .05$ vs. LONG.

Table 4 - Muscle oxygenation response during RPE-clamped exercise bouts showing mean data, standard deviation, and coefficients of variation.

							Coefficient of variation		
Variable					**Mean**	**SD**	**TV (%)**	**BAV (%)**	**WAV (%)**
ΔTSI%									
RPE 9	*a*	SHORT	*b*		-2.7	9.7	-355.6	-515.3	3.3
		MED			-4.5	12.0	-264.5	-278.0	-10.3
		LONG			-4.5	12.0	-264.5	-278.0	-62.2
RPE 13	*a*	SHORT	*b*		-12.9	12.3	-96.0	-97.5	-83.8
		MED			-14.2	13.6	-95.7	-98.0	-81.2
		LONG			-14.8	13.2	-89.4	-90.9	-50.6
RPE 17	*a*	SHORT	*d*		-16.0	12.5	-78.0	-23.6	-45.0
		MED			-16.9	12.8	-75.7	-76.8	-34.1
		LONG			-17.1	13.9	-81.4	-83.0	-39.6
ΔO_2Hb									
RPE 9	*a*	SHORT			2.6	7.6	292.5	299.9	-41.9
		MED			2.5	9.2	363.7	395.6	16.4
		LONG			2.6	7.6	292.5	299.9	25.1
RPE 13	*a*	SHORT			-8.4	10.9	-128.7	-128.8	-124.8
		MED			-8.4	10.3	-122.8	-124.8	112.3
		LONG			-9.5	10.4	-110.0	-112.4	-231.1
RPE 17	*a*	SHORT			-11.5	9.8	-84.9	-34.8	-133.9
		MED			-12.1	10.8	-89.2	-90.7	0.1
		LONG			-11.7	12.1	-103.8	-105.8	422.7
ΔHHb									
RPE 9	*a*	SHORT	*b*		5.7	5.6	98.0	100.2	33.7
		MED			6.4	7.3	114.6	114.8	38.9
		LONG			6.4	6.1	95.4	97.4	44.4
RPE 13	*a*	SHORT	*b,c*		13.2	11.4	86.9	82.1	33.6
		MED			14.7	10.7	72.8	72.7	28.8
		LONG			15.5	11.4	73.1	74.0	20.9
RPE 17	*a*	SHORT			15.0	9.9	66.2	20.6	18.1
		MED			16.8	11.7	69.6	69.6	20.2
		LONG			17.4	13.0	74.8	75.5	22.9

a = Significant difference observed between all session formats ($P < .001$). b = $P < .05$ vs LONG. c = $P < .001$ vs MED. d = $P < .05$ vs MED