1. *Title*:
The Self-Paced Submaximal Run Test: Associations with The Graded Exercise Test and Reliability.

2. *Submission type*:
Original Investigation

3. *Full names of the authors and institutional/corporate affiliations*:
Sangan, Hannah; School of Sport and Exercise Sciences, University of Kent, Kent, UK
Davidson, Glen; School of Sport and Exercise Sciences, University of Kent, Kent, UK
McLaren, Shaun; Department of Sport and Exercise Sciences, Durham University, Durham, UK
Hopker, James; School of Sport and Exercise Sciences, University of Kent, Kent, UK

4. *Contact details for the corresponding author. The name, institution, mail address, telephone and fax numbers, and e-mail address of the corresponding author*:
Hannah Sangan; School of Sport and Exercise Sciences, University of Kent at Medway, Medway Building, Chatham, Kent, ME4 4AG, England; hfs5@kent.ac.uk; +44 (0)1634 888814

5. *Preferred running head. Limited to 40 characters in length, including spaces*.
The Self-Paced Submaximal Run Test.

6. Abstract word count.
241 words

7. *Text-only word count. The total word count for the text only (excluding the abstract, acknowledgments, figure captions, and references) (limited to 3500 words).*
3500 words

8. *Number of figures and tables.*
3 Tables
4 Figures

## ABSTRACT

***Purpose.*** To assess the reliability and construct validity of a self-paced, submaximal run test ($SRT_{RPE}$) for monitoring aerobic fitness. The $SRT_{RPE}$ monitors running velocity (v), heart rate ($HR_{ex}$) and blood lactate concentration (B[La]) during three, 3-min stages prescribed by Ratings of Perceived Exertion (RPE) 10, 13 and 17.

***Methods***. Forty, (14 female), trained endurance runners completed a treadmill graded exercise test (GXT) for determination of maximal oxygen consumption ($\dot{V}O_{2max}$), velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and velocity at 2 $mmol \cdot L^{-1}$ (vLT1) and 4 $mmol \cdot L^{-1}$ (vLT2) B[La]. Within 7-days, participants completed the $SRT_{RPE}$. Convergent validity between the $SRT_{RPE}$ and GXT parameters was assessed through linear regression. Eleven participants completed a further two trials of the $SRT_{RPE}$ within a 72-hour period, to quantify test-retest reliability.

***Results.*** There were large correlations between v at all stages of the $SRT_{RPE}$ and $\dot{V}O_{2max}$ (r range = 0.57–0.63), $v\dot{V}O_{2max}$ (0.50–0.66) and vLT2 (0.51–0.62), with vRPE 17 displaying the strongest associations ($r > 0.60$). Intraclass correlation coefficients ($ICC_{3,1}$) were moderate to high for parameters, v (range = 0.76–0.84), $HR_{ex}$ (0.72–0.92) and $\%HR_{max}$ (0.64–0.89) at all stages of the $SRT_{RPE}$. The corresponding coefficients of variation were 2.5–5.6%. All parameters monitored at intensity RPE 17 displayed the greatest reliability.

***Conclusion.*** The $SRT_{RPE}$ was shown to be a valid and reliable test for monitoring parameters associated with aerobic fitness, displaying the potential of this non-invasive, time efficient test to monitor responses to endurance training.

## INTRODUCTION

The frequent and reliable monitoring of an individuals' responses to endurance training is an important component within the management of appropriate training stress and recovery[1].

Endurance performance is determined by the level of aerobic metabolism that can be maintained during a race (performance $\dot{V}O_2$)[2]. Performance $\dot{V}O_2$ is dictated by the upper limit for ATP production via oxidative phosphorylation ($\dot{V}O_{2max}$) and fraction of $\dot{V}O_{2max}$ that can be sustained (influenced by the lactate threshold and running economy)[2]. Although these parameters ($\dot{V}O_{2max}$, lactate threshold and running economy) are often analysed using a treadmill-based graded exercise test (GXT) to assess the construct of aerobic fitness in runners[2–4], their analysis for the purpose of monitoring acute within-subject responses to training has limitations. Specifically, in homogenous cohorts of runners, $\dot{V}O_{2max}$ has shown a low association with competitive performance [5,6] and low sensitivity to within-subject variation in performance following training[4]. Comparatively, velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and velocity at 4 $mmol \cdot L^{-1}$ blood lactate concentration (vLT2), has shown greater associations to within-individual changes in endurance running performance[4]. However, the traditional analysis of $v\dot{V}O_{2max}$ and vLT2 by the GXT requires expensive equipment, invasive procedures (blood sampling) and tester expertise, making this protocol inappropriate for regular monitoring and largely inaccessible.

Outside of a laboratory setting, aerobic fitness can be indirectly assessed through track-based multistage maximal exercise tests[7] or distance[4] and time[6] fixed time-trials. The submaximal components of aerobic fitness (upper limit of sustainable velocity) can be evaluated through the assessment of critical velocity from three, maximal effort time-trials over variable distances (1200m–3600m)[8]. However, although more accessible, these protocols require athletes to perform to exhaustion, making them inadequate for the regular monitoring of athletes' responses alongside training.

The Lamberts Submaximal Cycle Test (LSCT) is a practical exercise test which can be integrated into training as a warm-up. This test monitors performance output (power output/running velocity) and Ratings of Perceived Exertion (RPE) in response to three, short incremental exercise bouts (3–6-mins), fixed by a relative internal load of 60%, 80% and 90% heart rate maximum ($HR_{max}$)[9,10]. In an adaptation for runners, the velocity (v) monitored in an outdoor setting at 60%, 80% and 90% $HR_{max}$ has been shown to be positively associated with aerobic fitness parameters; $\dot{V}O_{2max}$ (r range = 0.58–0.75)[10] and vLT2 (0.79–0.89), suggesting that submaximal performance within this field-based test offers good construct validity in relation to aerobic fitness.

However, this protocol may be limited by monitoring individual's responses to fixed intensities prescribed by a $\%HR_{max}$. Firstly, this does not completely relinquish the requirement for athletes to complete a test to exhaustion. Furthermore, standardising the intensity of each stage by $\%HR_{max}$, likely leads to large inter-individual differences in metabolic, perceptual and performance responses (e.g. blood lactate responses and RPE), due to the inter-individual variations in the location of metabolic thresholds (lactate thresholds) between the stage intensities of 60%–90% $HR_{max}$[11].

In response to these limitations, we aim to explore the utility of a self-paced submaximal run test ($SRT_{RPE}$) which monitors v, heart rate ($HR_{ex}$) and blood lactate concentration (B[La]) responses to three, 3-min stages prescribed by RPE 10, 13 and 17[12]. The prescription of intensity by RPE may provide a practical alternative which will not require prior completion of a GXT to exhaustion and more validly represents the pacing demands of competitive endurance running. Importantly, the vLT2 has consistently been appraised by RPE values 12–14, regardless of sex or competitive level and despite large inter-individual differences in the $\%\dot{V}O_{2max}$ or $\%HR_{max}$ at this threshold[11,13]. Therefore, the particular intensities prescribed by the $SRT_{RPE}$ (RPE 10, 13 and 17) may provide better insight into the training effect on performance corresponding to below, approximately at, or above vLT2. Lastly, the use of 3-min stages is suggested as adequate to allow steady state v[14,15] to be reached, whilst minimising the time required for testing compared to similar submaximal protocols (i.e. ~6-mins less versus LSCT).

With these developments in mind[16], the potential effectiveness of the $SRT_{RPE}$ is dependent on its relative levels of validity and reliability[17,18]. As the $SRT_{RPE}$ aims to monitor a construct of fitness (aerobic fitness), validity can be determined by the magnitude of correlation between $SRT_{RPE}$ parameters and other accepted determinant of this fitness construct ($\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, vLT1 and vLT2)[18]. Furthermore, in order to evaluate the potential sensitivity of the $SRT_{RPE}$ to true changes in performance, the magnitude of two component sources of variability, systematic bias and random error will need to be quantified and accounted for[17].

Therefore, our study aims to investigate the construct validity of the $SRT_{RPE}$ through association with parameters of the GXT ($\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, vLT1 and vLT2). In addition, we aim to assess the test-retest reliability of v, $HR_{ex}$ and B[La] at each stage of the $SRT_{RPE}$.

## METHODS

**Participants.**

Forty endurance runners (14 females: 35 ± 3 yrs; $\dot{V}O_{2max}$ 49.00 ± 7.20ml·kg$^{-1}$·min$^{-1}$) (26 males: 38 ± 7 yrs; $\dot{V}O_{2max}$ 57.50 ± 5.63·kg$^{-1}$·min$^{-1}$) were recruited. All participants had over 2-years' experience of completing running-based endurance training (> 30km per week), with at least one-year competitive experience. All participants gave informed, written consent; completed a health questionnaire and confirmed that they had been free from injury in the previous 6-months. A sub-set of eleven runners within this cohort undertook additional tests required for reliability analysis (see **Design**) (5 females: 37 ± 8 yrs; $\dot{V}O_{2max}$ 50.00 ± 5.70 ml·kg$^{-1}$·min$^{-1}$5) (6 males: 35 ± 10 yrs; $\dot{V}O_{2max}$ 61.47 ± 6.43 ml·kg$^{-1}$·min$^{-1}$).The study was approved by the local University Research Ethics and Advisory Group (Prop 71_2017_18, Prop 107_2017_18, Prop 83_2018_19).

**Design.**

On their first visit all participants completed a treadmill-based maximal exercise test (GXT) to assess $\dot{V}O_{2max,}$ $HR_{max}$ and the running v at B[La] 2 mmol·L$^{-1}$ (vLT1) and 4 mmol·L$^{-1}$ (vLT2). Following 30-mins passive recovery, a familiarisation of the $SRT_{RPE}$ was completed. On their second visit, > 2-days after and within 1-week of visit 1, participants performed the $SRT_{RPE}$. For analysis of reliability a subset of participants (n = 11) completed an additional visit (> 2-days and within 72-hours of visit 2) in which two trials of the $SRT_{RPE}$ were performed, separated by 30-mins passive recovery.

**Maximal incremental run test**.

Participants undertook a two-phase treadmill based (H/P/Cosmos, Nussdorf-Traunstein, Germany) GXT for the assessment of vLT1 and vLT2 (Phase-one) and to determine $\dot{V}O_{2max}$, v$\dot{V}O_{2max}$ and $HR_{max}$ (Phase-two). Before initiation of the test, all participants read the standardised instructions for reporting the RPE (6-20) scale[12]. Participants completed a 5-min warm up at an intensity representing the v at which walking transitioned to running (range 7–9 km·h$^{-1}$). Phase-one comprised of 5–7 submaximal intervals with v increasing by 1 km·h$^{-1}$ every 4-mins, initiated at the v completed during warm-up. In the 1-min recovery between intervals, RPE (6–20)[12] was reported and a 5µL fingertip capillary blood sample was taken to assess B[La] (Biosen C-Line, EKF Diagnostics, Penarth, UK). Phase-one was terminated when B[La] exceeded 4 mmol·L$^{-1}$. Phase-two proceeded following a 10-min recovery; initiated at the same starting v as phase-one, increasing v by 0.5

km·h$^{-1}$ every 1-min until volitional exhaustion. Maximal effort was accepted by attainment of at least two of the following criteria: $HR_{ex}$ within 10 beats·min$^{-1}$ of age-predicted maximum; RER ≥ 1.10; RPE ≥ 17; and B[La] ≥ 8 mmol·L$^{-1}$. $\dot{V}O_{2max}$ was determined as the highest 30-second average oxygen uptake[19] and v at this point ($\dot{V}O_{2max}$) was considered the v$\dot{V}O_{2max}$. $HR_{ex}$ was recorded at a second by second frequency; Heart rate maximum ($HR_{max}$) was considered the highest 5-second average recorded $HR_{ex}$ (Polar T31 Instruments, Kempele, Finland). The first and second lactate threshold (vLT1, vLT2) was calculated as the v at which B[La] reached 2 mmol·L$^{-1}$ and 4mmol·L$^{-1}$ respectively (Biosen C-line, EKF diagnostic, Barleben, Germany). Mean laboratory conditions were: Temperature 19.2ºC (range =18ºC–20.2ºC), Humidity 749 to 761 mmHg.

**The Self-paced Submaximal Run Test ($SRT_{RPE}$)**

The $SRT_{RPE}$ comprised of three, 3-min stages interspersed by 1-min recovery, performed on an outdoor, synthetic, 400m running track (Figure 1). Intensity was prescribed by RPE 10, 13 and 17[12]. Participants were instructed to control their pace based upon a set of standardised instructions, which were re-read to them prior to each $SRT_{RPE}$[12]. During each 3-min stage, participants v (km·h$^{-1}$) and $HR_{ex}$ (beats·min$^{-1}$) were recorded using a GPS monitor (1Hz sampling rate; Polar V800) and $HR_{ex}$ monitor (1Hz sampling rate; Polar H7). The watch-face was covered during testing using a sleeve or sweat-band. A whistle was blown to signify the end of each 3-min stage. The first 120-seconds of v and $HR_{ex}$ data was excluded from final analysis as steady state has previously been established to occur after this point[14,20]. During the 1-min recovery between stages, a 5μL sample of whole fresh capillary blood was collected from the fingertip and subsequently analysed for B[La] (Biosen C-line, EKF diagnostic, Barleben, Germany). Mean outdoor testing conditions were: Windspeed 1.2 m/s (range = 0.4 m/s–1.8 m/s), temperature 8.5 ºC (range = 4ºC–13ºC)

**Statistical Analysis**

All data was assessed for normality of distribution prior to statistical analysis using the Shapiro-Wilk test. Raw data for v (km·h$^{-1}$), $HR_{ex}$ (beats·min$^{-1}$), %$HR_{max}$ and B[La] (mmol.L$^{-1}$) were summarised as mean ± SD for each three trials. Prior to analysis, all data were log-transformed to reduce bias associated with non-uniformity of error and were subsequently back-transformed to obtain a reliability statistic in raw and percentage units. This was with the exception of %$HR_{max}$, where raw units are already expressed in percentage points.

A regression model, with v for each stage of the $SRT_{RPE}$ as the independent variable and parameters of the GXT ($\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, vLT1 and vLT2) as the dependent variable(s) was computed to examine the construct validity of the $STR_{RPE}$. v was selected as the only independent variable because this is the primary outcome measure of the $STR_{RPE}$, where intensity is fixed according to RPE. The analysis was carried out for all participants and for male and female subgroups separately. The strength of the relationships were assessed by a Pearson's product–moment correlation coefficient (r) while the shared variance was given as the coefficient of determination ($R^2$). Standard errors of the estimate (SEE) were used to represent random bias in raw and %units (derived from analysis of the log-transformed data for %units). Uncertainty in estimates, and ranges of values compatible with the data sample, assumptions and statistical models, were expressed as 90% confidence intervals (CI)[21]. Intervals for Pearsons r and SEE values were derived from an F and chi-squared distributions, respectively. The strength of correlations were determined using the following criteria: 0.1 (trivial), 0.1–0.3 (small), 0.3–0.5 (moderate), 0.5–0.7 (large), 0.7–0.9 (very large), and 0.9–1.0 (almost perfect)[10]. Analysis was performed using Microsoft Excel (Version 16.28, Microsoft, Redmond, WA, USA), using a spreadsheet downloaded from (sportsci.org/2015/ValidRely.htm).

To examine the re-test reliability of $STR_{RPE}$, the systematic change in each outcome measure was given as the mean difference between consecutive trials. A minimum effect test (MET) provided a practical, probabilistic interpretation of the mean change in each outcome measure between trial 1–2 and 2–3[24]. For v and internal load measures ($HR_{ex}$ and B[La]), we used a smallest important threshold of 0.2 multiplied by the pooled, between-subject SD of all three trials, alpha set at $P_{MET} < 0.05$. Typical error (TE, also expressed as a coefficient of variation [CV]) was also calculated between consecutive trials, estimated as the standard deviation of change scores divided by the square root of 2. These values were then pooled to give the overall TE and CV. In addition, Intraclass correlation coefficients ($ICC_{3,1}$) was assessed using a 2-way mixed-effects model [22]. Confidence intervals for the mean change were calculated using a t-distribution. For TE, CI were calculated using the chi-squared distribution and for the $ICC_{3,1}$ an F-distribution was used[23]. The thresholds for interpretation of the magnitude of $ICC_{3,1}$ were : >0.99 (extremely high), 0.90–0.99 (very high), 0.75–0.90 (high), 0.50–0.75 (moderate), 0.20–0.50 (low), <0.20 (very low)[25].Analysis was performed using Microsoft Excel (Version 16.28, Microsoft, Redmond, WA, USA),using a spreadsheet downloaded from (sportsci.org/2015/ValidRely.htm).

## RESULTS

### Group performance in GXT and SRT$_{RPE}$.

Table 1 displays the mean ± SD results for the GXT for both male and female participants. Table 2 displays the physiological responses (HR$_{ex}$, %HR$_{max}$ and B[La]) and v associated with each stage of the SRT$_{RPE}$. Each stage was considered sub-maximal based upon prior outlined criterion for maximal effort (see **Maximal incremental run test**), with intensity prescribed by RPE 10, 13 and 17 corresponding to; 74.7 ± 6.3%, 81.4 ± 7.0% and 88.7 ± 6.1% of HR$_{max}$ and 1.5 ± 0.4 mmol.L$^{-1}$, 1.8 ± 0.6 mmol.L$^{-1}$ and 3.5 ± 1.6 mmol.L$^{-1}$ respectively. As shown in Figure 2, the mean absolute difference (km·h$^{-1}$) between vLT2 evaluated by GXT and v at each stage of the SRT$_{RPE}$ was; -2.51±1.58 km·h$^{-1}$ for RPE 10, -0.34 ± 1.52 km·h$^{-1}$ for RPE 13 and 1.53 ±1.40 km·h$^{-1}$ for RPE 17.

### Concurrent validity of the SRT$_{RPE}$.

Table 3 and Figure 3 display the inferential validity statistics for parameters of the SRT$_{RPE}$ with parameters of the GXT ($\dot{V}O_{2max}$, v$\dot{V}O_{2max}$, vLT1 and vLT2). For all participants (n = 40), RPE 17 had the strongest association with parameters of the GXT (r range = 0.60–0.66, large). Standard errors of the estimate were ~8–12% for all measures. Table 3 shows the relationship between v at each stage of the SRT$_{RPE}$ and parameters of the GXT for each sex.

### Test-retest reliability of the SRT$_{RPE}$.

Table 2 displays the inferential statistics for the test-retest reliability of the SRT$_{RPE}$. The MET revealed no meaningfully changes in v, HR$_{ex}$, %HR$_{max}$ and B[La] between trial 1–2 and 2–3 ($P_{MET}$ >0.05). Figure 4 illustrates individual values for v in trial 1, 2 and 3 for each SRT$_{RPE}$ intensity.

CV's for v ranged from 3.9%–5.5%, and from 2.5%–5.6% for HR$_{ex}$, with variation consistently lower at greater submaximal intensities. The typical error for %HR$_{max}$ ranged 2.2%–4.0%. B[La] displayed the highest CVs' ranging from 24.8–28.6%. ICC$_{3.1}$'s were moderate to high for parameters v (range = 0.76–0.84), HR$_{ex}$ (0.72–0.92) and %HR$_{max}$ (0.64–0.89) at all stages of the SRT$_{RPE}$. B[La] displayed the lowest ICC$_{3.1}$ (0.26–0.69).

## DISCUSSION.

Our study sought to assess the construct validity and reliability of parameters of the novel SRT$_{RPE}$. Results showed large associations (r range = 0.50–0.66) between v at each stage of the SRT$_{RPE}$ and parameters of the GTX, suggesting results of the SRT$_{RPE}$ can validly reflect an individuals' level of aerobic fitness. A moderate to high reliability for parameters: v (ICC

range = 0.76–0.84), $HR_{ex}$ (0.72–0.92) and $\%HR_{max}$ (0.64–0.89) was measured during self-paced, submaximal efforts.

The v at RPE 10, 13 and 17 showed large associations with $v\dot{V}O_{2max}$ ($r$ = 0.50–0.66) and vLT2 ($r$ = 0.50–0.62) (Table 2); suggesting $SRT_{RPE}$ is able to discriminate between individuals of varying aerobic fitness. Previous authors have described greater associations between LSCT and GXT parameters[9], which may result from their use of standardised, laboratory conditions. However, Vesterinen[10] showed the v at intensities 60%, 80% and 90% $HR_{max}$ recorded in outdoor conditions, still displayed greater correlations with $v\dot{V}O_{2max}$ ($r$ range = 0.74–0.83) and vLT2 (0.78–0.89) than the current study. This discrepancy may result from differing methods of assessments of $v\dot{V}O_{2max}$ and vLT2 between studies, or disparity in the duration in intervals of the GXT (4-mins) and $SRT_{RPE}$ (3-mins) analysed in the current study. We cannot comment if greater error in the $SRT_{RPE}$ caused lower associations as the reliability of the submaximal exercise test used by Vesterinen[10] was not reported.

The analysis of the regression error (SEE) shows for example, for a given vRPE 17 the associated $\dot{V}O_{2max}$ may vary by 9.0% (7.6–11.3%) and vLT2 by 10.0% (8.3–12.5%). The magnitude of this error is greater than previously identified meaningful differences for both $\dot{V}O_{2max}$[4] and vLT2[26], suggesting that v measured during the $SRT_{RPE}$ would not accurately predict the treadmill based GXT results.

Our results show that when separated, female participants displayed greater associations between our independent and dependent variables resulting from lower values of v in $SRT_{RPE}$ and GXT parameters, when compared to males who 'clustered' higher on both (Table 3, Figure 3). These results highlight the potential constraints in generalising overall correlation results to more homogeneous subsets (e.g. elite cohorts)[17]. In addition, our results provide further evidence that runners homogenous in $\dot{V}O_{2max}$ show variability in performance v, explaining the low association between $\dot{V}O_{2max}$ and endurance performance in such cohorts[5,6] and support the preferential use of field-based exercise tests for monitoring[6].

Our results support previous evidence that RPE 10, 13 and 17 correspond to intensities below, approximately at, or above vLT2 (Figure 2)[11,13]. Of the 40 participants, only one regulated vRPE 10 above their vLT2 (+0.43 $km \cdot h^{-1}$) and 3 participants regulated vRPE 17 below their vLT2 (each -0.90, -0.64 and -0.23 $km \cdot h^{-1}$ below vLT2). This standardisation of intensity may aid the interpretation of responses to endurance training interventions which specifically target adaptations around these metabolic thresholds.

Results revealed no meaningful difference for v, $HR_{ex}$, $\%HR_{max}$ and B[La] between trials 1-2 and 2-3 ($P_{MET}$ >0.05) providing no evidence of systematic bias[17]. The study may be limited in performing two trials (2-3) on the same day[23]. However, evidence of low variability between trials 2-3 suggests that the $SRT_{RPE}$ can reliably be used multiple times within a day which may benefit monitoring of responses to morning and evening training. The relative reliability of v during $SRT_{RPE}$ is comparable to previous research describing the variability in 2-mins track-based v ($km \cdot h^{-1}$) produced at RPE 10 (6.4% ± 3.1%), RPE 13 (2.9% ± 1.1%) and RPE 17 (2.9% ± 0.8%)[15]. Together our results suggest that 3-mins is sufficient in allowing participants to reach and maintain a steady state v[14] based on RPE; minimising the time required for testing compared to similar submaximal protocols (i.e. ~6-mins less versus LSCT).

Field-based maximal exercise tests such as distance fixed time-trials are often preferred for athlete monitoring due to their high ecological validity and reliability[6,16]. Previously, the average v for maximal effort 1500m and 5km time-trials have displayed CV's of 2.0% (95% CI: 1.2–4.0%) and 3.3% (95% CI: 2.1–6.8%) respectively[27].As such, the within-individual variability of vRPE 17 seen during the current study is comparible (CV = 3.9%, 90% CI: 3.0–5.7%). This provides evidence that the $SRT_{RPE}$, which provides a more time-efficient and less physically demanding alternative to maximal performance tests, is also comparable in sensitivity.

The potential sensitivity of the $SRT_{RPE}$ can be explored by comparing the magnitude of measurement error in the test (noise) to prior reported meaningful changes in these parameters (signal)[17,23]. Previous literature, assessing a comparable cohort, reported 5.1% improvement in average v over 5000m, on an outdoor track following 6-weeks of endurance training. Treadmill based submaximal v (vLT2) has similarly been shown to vary by 4.4–6.3% following 6-week's training[3,4].This magnitude of expected change (signal) is greater than the CV (noise) for v at all stages of the $SRT_{RPE}$, suggesting an acceptable sensitivity of the test[15,22].

The utility of $HR_{ex}$ to sensitively monitor aerobic fitness has been debated due to its sensitivity to confounding variables outside of training stress[20]. Previous research has shown a day-to-day variation in $HR_{ex}$ of 6–8 $beats \cdot min^{-1}$ at intensities 60–80% maximal and 3–5 $beats \cdot min^{-1}$ at intensities 80–90% of maximal[28]. This is comparable to the random error found in the current study (Table 2). Additionally, previous research reported a comparable magnitude of variability (CV range = 2.3–7.0%) in % $HR_{max}$ during self-paced combined arm and leg cycling at RPE 9, 13 and 17[29]. The variability shown in the current study should be accounted for when determining true-change in this parameter. The measurement error was greatest for B[La] with a CV range of 24.8–28.6%. This high magnitude of variation has similarly been reported between repeated 1000m efforts at RPE 17 (CV = 16.8%)[30]. Our results suggest that B[La] during the $SRT_{RPE}$ may be too  unreliable for monitoring purposes.

Future research aiming to monitor individual's responses using the $SRT_{RPE}$ should be cautious that results may be influenced by environmental conditions and reliability of the GPS and $HR_{ex}$ monitors used. It would be advised to complete a separate reliability analysis if conditions or equipment vary from those used in the current study.

## PRACTICAL APPLICATIONS:

- Large between-subject correlations between v at each RPE stage and GXT suggest that these measures are convergent of a similar fitness construct (aerobic capacity) and the $STR_{RPE}$ could therefore be a more accessible and practical test to discriminate between participants.
- Modest error between v at each RPE stage and GTX parameters suggests the $SRT_{RPE}$ should be used cautiously to predict GXT variables such as vLT2 and warrants further investigation for this use.
- Low TE/CV's for v selected at each RPE intensity, suggest that true individual changes can be detected with reasonable accuracy.

## CONCLUSIONS:

The novel $SRT_{RPE}$ shows large associations with GXT parameters, suggestive of construct validity. The $SRT_{RPE}$ test shows acceptable reliability over repeated trials. Future research should examine response to the $SRT_{RPE}$ across participants with a broader range of aerobic capacities and its sensitivity to within-individual changes in fitness.

## AKNOWLEDGEMENTS

N/A

**REFRENCES**


1. Coutts A, Kempton T, Crowcroft S. Coutts, A. J., Crowcroft, S., & Kempton, T. (2018). Developing athlete monitoring systems: Theoretical basis and practical applications. In M. Kellmann & J. Beckmann (Eds.), Sport, Recovery and Performance: Interdisciplinary Insights (pp. 19-32). Abingdon. 2018;(October):19-32.
2. Bassett DR, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. / Facteurs limitants de la consommation maximale d'oxygene et determinants de la performance d'endurance. *Med Sci Sport Exerc*. 2000;32(1):70-84.
3. Carter H, Jones AM, Doust JH. Effect of 6 weeks of endurance training on the lactate minimum speed. *J Sports Sci*. 1999;17(12):957-967. doi:10.1080/026404199365353
4. Stratton E, O'brien BJ, Harvey J, et al. Treadmill velocity best predicts 5000-m run performance. *Int J Sports Med*. 2009;30(01):40-45.
5. Conley, Douglas L. GS. Running economy and distance running performance of highly trained athletes. *Med Sci Sport Exerc*. 1980;12(5):357-360. doi:10.1249/00005768-198012050-00010
6. Alvero-Cruz JR, Carnero EA, Giráldez García MA, et al. Cooper Test Provides Better Half-Marathon Performance Prediction in Recreational Runners Than Laboratory Tests. *Front Physiol*. 2019;10(November):1-9. doi:10.3389/fphys.2019.01349
7. Uger L, Boucher R. An indirect continuous running multistage field test: the Universite de Montreal track test. *Can J Appl Sport Sci*. 1980;5:77-84.
8. Galbraith A, Hopker JG, Jobson SA, Passfield L. A novel field test to determine critical speed. *J Sports Med Doping Stud*. 2011;1(1):1-4.
9. Lamberts RP, Swart J, Noakes TD, Lambert MI. A novel submaximal cycle test to monitor fatigue and predict cycling performance. *Br J Sports Med*. 2011;45(10):797-804. doi:10.1136/bjsm.2009.061325
10. Vesterinen V, Nummela A, Äyrämö S, et al. Monitoring training adaptation with a submaximal running test under field conditions. *Int J Sports Physiol Perform*. 2016;11(3):393-399. doi:10.1123/ijspp.2015-0366
11. Seip RL, Snead D, Pierce EF, Stein P, Weltman A. Perceptual Responses and Blood Lactate Concentration: Effect of Training State. *Med Sci Sports Exerc*. 1991;23(1):80-87.
12. Borg G. Borg ' s Perceived Exertion And Pain Scales. *Champaign, ILHuman Kinet*. Published online 1998.

13. Demello JJ, Cureton KJ, Boineau RE, Singh MM. Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. *Med Sci Sports Exerc*. 1987;19(4):354-362. doi:10.1249/00005768-198708000-00006
14. Carter H, Pringle JSM, Jones AM, Doust JH. Oxygen uptake kinetics during treadmill running across exercise intensity domains. *Eur J Appl Physiol*. 2002;86(4):347-354. doi:10.1007/s00421-001-0556-2
15. Lim W, Lambrick D, Mauger A, Woolley B, Faulkner J. The effect of trial familiarisation on the validity and reproducibility of a field-based self-paced VO2max test. *Biol Sport*. 2016;33(3):269-275. doi:10.5604/20831862.1208478
16. Thorpe RT, Atkinson G, Drust B, Gregson W. Monitoring fatigue status in elite team-sport athletes: implications for practice. *Int J Sports Physiol Perform*. 2017;12(s2):S2-27.
17. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sport Med*. 1998;26(4):217-238. doi:10.2165/00007256-199826040-00002
18. Currell K, Jeukendrup AE. Validity, reliability and sensitivity of measures of sporting performance. *Sport Med*. 2008;38(4):297-316.
19. ACSM. *ACSM Guidelines for Exercise Testing and Prescription*. Vol 37.; 2014. doi:9781609136055
20. Achten J, Jeukendrup AE. Heart rate monitoring. *Sport Med*. 2003;33(7):517-538.
21. Greenland S. Valid P-Values Behave Exactly as They Should: Some Misleading Criticisms of P-Values and Their Resolution With S-Values. *Am Stat*. 2019;73(sup1):106-114. doi:10.1080/00031305.2018.1529625
22. Shrout PE, Fleiss JL. Intraclass correlations: Uses in assessing rater reliability. *Psychol Bull*. 1979;86(2):420-428. doi:10.1037/0033-2909.86.2.420
23. Hopkins WG. Measures of reliability in sports medicine and science. *Sport Med*. 2000;30(1):1-15. doi:10.2165/00007256-200030010-00001
24. Murphy KR, Myors B. Testing the hypothesis that treatments have negligible effects: Minimum-effect tests in the general linear model. *J Appl Psychol*. 1999;84(2):234-248. doi:10.1037/0021-9010.84.2.234
25. Malcata RM, Vandenbogaerde TJ, Hopkins WG. Using athletes' world rankings to assess countries' performance. *Int J Sports Physiol Perform*. 2014;9(1):133-138. doi:10.1123/IJSPP.2013-0014
26. Altmann S, Neumann R, Woll A, et al. Using submaximal exercise heart rate for monitoring

cardiorespiratory fitness changes in professional soccer players : A replication study. Published online 2020.
27. Laursen PB, Francis GT, Abbiss CR, Newton MJ, Nosaka K. Reliability of time-to-exhaustion versus time-trial running tests in runners. *Med Sci Sports Exerc*. 2007;39(8):1374-1379. doi:10.1249/mss.0b013e31806010f5
28. Lamberts RP, Lemmink KAPM, Durandt JJ, Lambert MI. Variation in Heart Rate During Submaximal Exercise: Implications for Monitoring Training. *J Strength Cond Res*. 2004;18(3):641. doi:10.1519/1533-4287(2004)18<641:VIHRDS>2.0.CO;2
29. Hill M, Puddiford M, Talbot C, Price M. The validity and reproducibility of perceptually regulated exercise responses during combined arm + leg cycling. *Eur J Appl Physiol*. Published online 2020. doi:10.1007/s00421-020-04444-z
30. Edwards AM, Bentley MB, Mann ME, Seaholme TS. Self-pacing in interval training: A teleoanticipatory approach. *Psychophysiology*. 2011;48(1):136-141. doi:10.1111/j.1469-8986.2010.01034.x

## FIGURE CAPTIONS

**Fig.1** Schematic of the $SRT_{RPE.}$

**Fig.2** Box-plot for the difference in velocity (v) selected at RPE 10,13 and 17 and velocity at 4 mmol·$L^{-1}$ B[La] (vLT2). The box defines the upper and lower quartile and the median for the absolute difference in velocity (km·$h^{-1}$). Whiskers show the minimum and maximum differences.

**Fig.3** Regression analysis between velocity selected (v) at RPE 10 (**A**) RPE 13 (**B**) and RPE 17 (**C**) with velocity and maximal oxygen capacity ($v\dot{V}O_{2max}$) and velocity at 4 mmol·$L^{-1}$ B[La] (vLT2). Group correlations (n=40) females (n = 14), male (n=26). Pearson's product moment correlation (r) with 90% confidence intervals.

**Fig.4** Individual raw values for the velocity at each stage of the $SRT_{RPE}$ over three repeated trials.

**Table 1. Results for the Graded Exercise Test (GXT) (mean ± SD). (n = 40)**

| | Female (n = 14) | Male (n = 26) |
|---|---|---|
| $\dot{V}O_{2max}$ (ml·kg·min$^{-1}$) | 49.00 ± 7.20 | 57.50 ± 5.63 |
| $v\dot{V}O_{2max}$ (km·h$^{-1}$) | 13.80 ± 1.38 | 16.09 ± 1.26 |
| vLT1 (km·h$^{-1}$) | 10.75 ± 1.24 | 12.04 ± 1.34 |
| vLT2 (km·h$^{-1}$) | 12.31 ± 1.25 | 14.10 ± 1.38 |

Abbreviations: maximal oxygen consumption ($\dot{V}O_{2max}$), velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and velocity at 2 mmol.L$^{-1}$ (vLT1) and 4 mmol.L$^{-1}$ (vLT2).

**Table 2. Test-retest reliability of the parameters of the self-paced submaximal run test, over three repeated trials. (n = 11)**

| | **Mean ± SD** | | | | **Reliability Statistics (90% CI)** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Trial** | | | | **Systematic Change** | | | | |
| | **1** | **2** | **3** | **Overall** | **Trial 2–1** | **Trial 3–2** | **TE** | **$CV_{TEM\%}$** | **$ICC_{3,1}$** |
| **v (km·h$^{-1}$)** | | | | | | | | | |
| RPE 10 | 10.86 ± 1.18 | 10.71 ± 0.98 | 10.86 ± 1.17 | 10.81 ± 1.11 | -0.15 (-0.60–0.31) | 0.15 (-0.32–0.62) | 0.60 (0.47–0.88) | 5.5 (4.3–8.1) | 0.76 (0.49–0.90) |
| RPE 13 | 12.63 ± 1.06 | 12.83 ± 1.10 | 12.85 ± 1.07 | 12.77 ± 1.08 | 0.20 (-0.21–0.62) | 0.02 (-0.42–0.46) | 0.55 (0.44–0.81) | 4.5 (3.5–6.6) | 0.78 (0.53–0.91) |
| RPE 17 | 15.02 ± 1.41 | 15.06 ± 1.25 | 14.74 ± 1.00 | 14.94 ± 1.23 | 0.04 (-0.38–0.46) | -0.32 (-0.75–0.12) | 0.55 (0.43–0.81) | 3.9 (3.5–6.6) | 0.83 (0.64–0.94) |
| **$HR_{ex}$ (beats·min$^{-1}$)** | | | | | | | | | |
| RPE 10 | 132.6 ± 10.4 | 136.5 ± 13.6 | 133.2 ± 14.0 | 134.1 ± 12.8 | 3.9 (-1.9–9.8) | -3.3 (-8.7–2.2) | 7.3 (5.8–10.7) | 5.6 (4.4–8.3) | 0.72 (0.44–0.89) |
| RPE 13 | 147.3 ± 11.1 | 146.7 ± 15.0 | 144.3 ± 15.7 | 146.1 ± 14.1 | -0.5 (-5.5–4.5) | -2.4 (-7.3–2.4) | 6.3 (5.0–9.3) | 4.7 (3.7–6.9) | 0.83 (0.63–0.94) |
| RPE 17 | 160.5 ± 12.4 | 161.0 ± 13.1 | 156.3 ± 13.4 | 159.3 ± 13.0 | 0.4 (-2.5–3.4) | -4.6 (-8.0–-1.3) | 4.1 (3.2–6.0) | 2.5 (2.0–3.7) | 0.92 (0.82–0.97) |
| **$\%HR_{max}$** | | | | | | | | | |
| RPE 10 | 73.9 ± 5.7 | 76.0 ± 6.4 | 74.2 ± 6.8 | 74.7 ± 6.3 | 2.1 (-1.0–5.3) | -1.8 (-4.8–1.2) | 4.0 (3.2–5.9) | | 0.64 (0.32–0.85) |
| RPE 13 | 82.1 ± 5.5 | 81.8 ± 7.8 | 80.4 ± 7.5 | 81.4 ± 7.0 | -0.3 (-3.1–2.5) | -1.4 (-4.1–1.2) | 3.5 (2.8–5.2) | | 0.79 (0.55–0.92) |
| RPE 17 | 89.4 ± 5.4 | 89.7 ± 6.4 | 87.1 ± 6.4 | 88.7 ± 6.1 | 0.3 (-1.3–1.9) | -2.6 (-4.4–-0.8) | 2.2 (1.8–3.3) | | 0.89 (0.75–0.96) |
| **B[La](mmol.L$^{-1}$)** | | | | | | | | | |
| RPE 10 | 1.5 ± 0.4 | 1.6 ± 0.5 | 1.8 ± 0.4 | 1.6 ± 0.4 | 0.0 (-0.2–0.3) | 0.2 (-0.1–0.6) | 0.4 (0.3–0.6) | 24.8 (19.1–38.3) | 0.26 (-0.11–0.63) |
| RPE 13 | 1.8 ± 0.6 | 1.8 ± 0.6 | 2.3 ± 0.7 | 2.0 ± 0.6 | 0.1 (-0.3–0.5) | 0.5 (0.0–0.9) | 0.6 (0.4–0.8) | 32.2 (24.6–50.5) | 0.27 (-0.10–0.64) |
| RPE 17 | 3.5 ± 1.6 | 2.9 ± 1.1 | 3.7 ± 1.1 | 3.4 ± 1.3 | -0.6 (-1.1–-0.1) | 0.9 (0.2–1.6) | 0.8 (0.6–1.1) | 28.6 (22.0–44.6) | 0.69 (0.39–0.87) |

Abbreviations: RPE ( Rating of perceived exertion) v (Velocity) $HR_{ex}$ (Exercising heart rate) $HR_{max}$ (Heart rate maximum) B[La] (Blood lactate concentration) TEM (Test error of the measurement) $CV_{TEM\%}$ (TEM as a Coefficient of variation) $ICC_{1,3}$ (Intraclass correlation coefficient).

**Table 3. Regression analysis between the velocity measured during self-paced submaximal running test and parameters of the graded exercise test. (n = 40)**

| | r (90% CI) | $R^2$ | SEE raw (90% CI) | SEE % (90% CI) |
|---|---|---|---|---|
| **$\dot{V}O_{2max}$ (ml·kg$^{-1}$·min$^{-1}$)** | | | | |
| RPE 10 | 0.57 (0.36–0.73) | 0.33 | 6.4 (5.4–8.0) | 12.3 (10.3–15.4) |
| RPE 13 | 0.56 (0.35–0.72) | 0.31 | 6.5 (5.5–8.0) | 12.4 (10.4–15.6) |
| RPE 17 | 0.63 (0.44–0.77) | 0.39 | 6.1 (5.2–7.6) | 11.6 (9.7–14.6) |
| **v$\dot{V}O_{2max}$ (km·h$^{-1}$)** | | | | |
| RPE 10 | 0.50 (0.27–0.67) | 0.25 | 1.5 (1.3–1.9) | 10.6 (8.9–13.2) |
| RPE 13 | 0.57 (0.36–0.72) | 0.32 | 1.5 (1.2–1.8) | 10.0 (8.4–12.5) |
| RPE 17 | 0.66 (0.49–0.79) | 0.44 | 1.3 (1.1–1.6) | 9.0 (7.6–11.3) |
| **vLT1 (km·h$^{-1}$)** | | | | |
| RPE 10 | 0.46 (0.22–0.64) | 0.21 | 1.4 (1.2–1.7) | 12.5 (10.4–15.7) |
| RPE 13 | 0.52 (0.30–0.69) | 0.27 | 1.4 (1.1–1.7) | 12.0 (10.0–15.0) |
| RPE 17 | 0.60 (0.40–0.75) | 0.36 | 1.3 (1.1–1.6) | 11.2 (9.4–14.0) |
| **vLT2 (km·h$^{-1}$)** | | | | |
| RPE 10 | 0.51 (0.28–0.68) | 0.26 | 1.4 (1.2–1.7) | 11.0 (9.2–13.8) |
| RPE 13 | 0.57 (0.36–0.72) | 0.32 | 1.4 (1.1–1.7) | 10.5 (8.8–13.2) |
| RPE 17 | 0.62 (0.43–0.76) | 0.39 | 1.3 (1.1–1.6) | 10.0 (8.3–12.5) |

Abbreviations: maximal oxygen consumption ($\dot{V}O_{2max}$), velocity at $\dot{V}O_{2max}$ (v$\dot{V}O_{2max}$) and velocity at 2 mmol.L$^{-1}$ (vLT1) and 4 mmol.L$^{-1}$ (vLT2), v (Velocity) RPE (Rating of perceived exertion) SEE ( Standard error of the estimate).

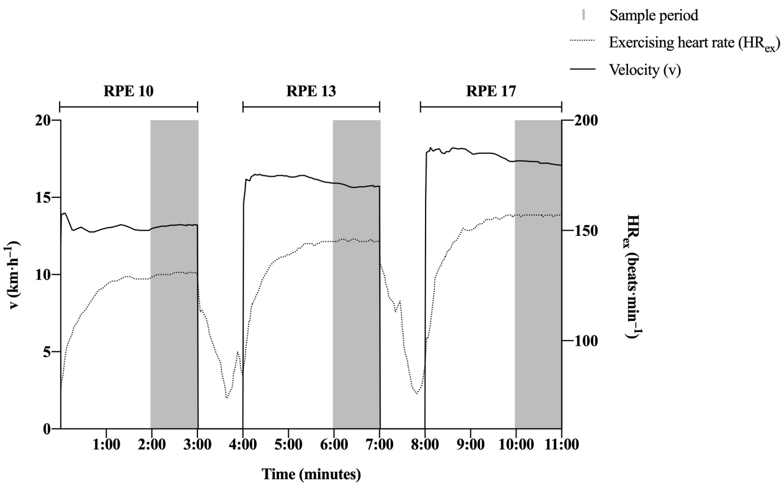



Figure 1

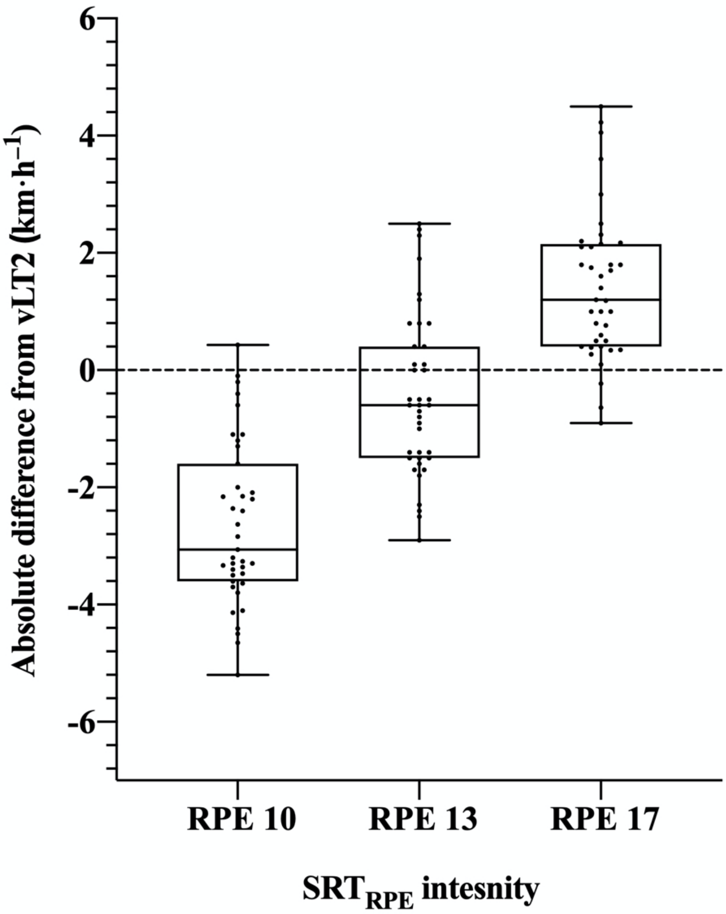



Figure 2

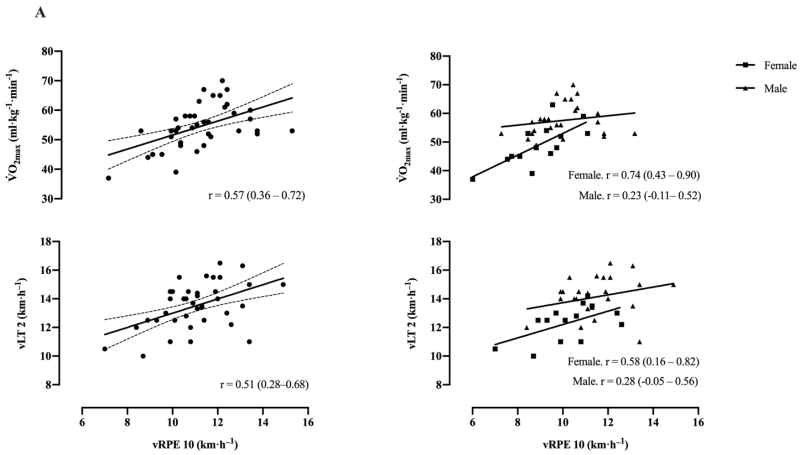



Figure 3A

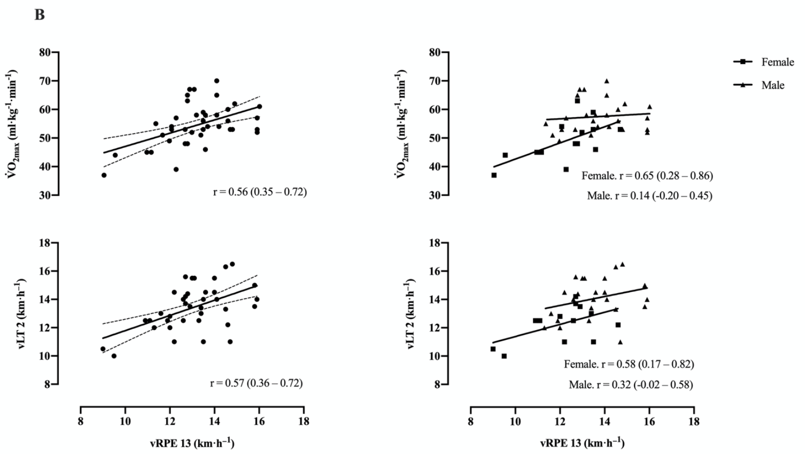



Figure 3B

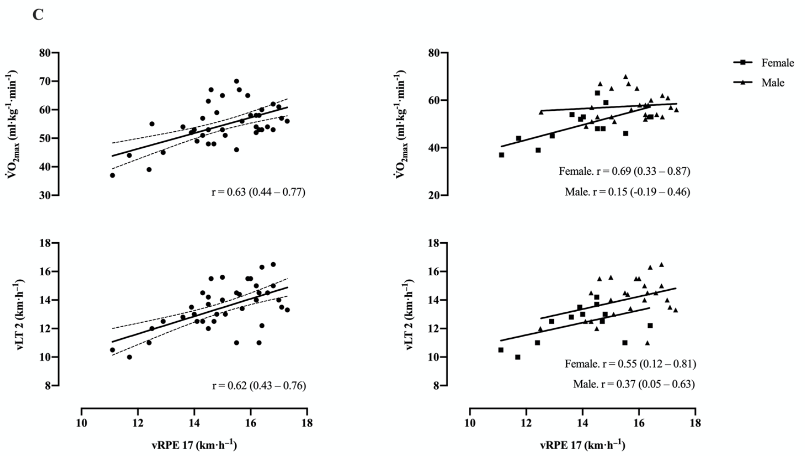
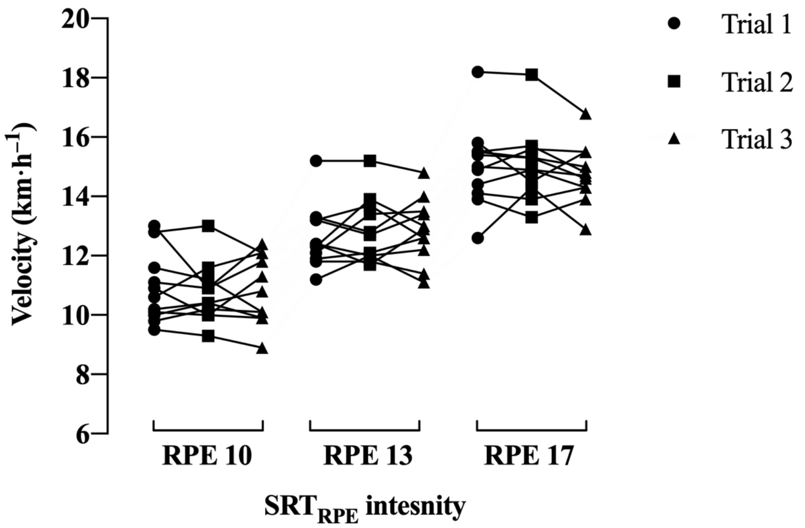



Figure 3C



Velocity (km·h$^{-1}$)
20
18
16
14
12
10
8
6
RPE 10
RPE 13
RPE 17
SRT$_{RPE}$ intesnity
Trial 1
Trial 2
Trial 3


Figure 4