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**Author(s):** Nuutila, Olli-Pekka; Matomäki, Pekka; Kyröläinen, Heikki; Nummela, Ari

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## Predicting running performance and adaptations from intervals at maximal sustainable effort

Olli-Pekka Nuuttila, Pekka Matomäki, Heikki Kyröläinen, Ari Nummela.

Affiliations below.

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### Abstract:

This study examined the predictive quality of intervals performed at maximal sustainable effort to predict 3-km and 10-km running times. In addition, changes in interval performance and associated changes in running performance were investigated. Either 6-week (10-km group, n = 29) or 2-week (3-km group, n = 16) interval training periods were performed by recreational runners. A linear model was created for both groups based on the running speed of the first 6x3-min interval session and the test run of the preceding week (T1). The accuracy of the model was tested with the running speed of the last interval session and the test run after the training period (T2). Pearson correlation was used to analyze relationships between changes in running speeds during the tests and interval sessions. At T2, the mean absolute percentage error of estimate for 3-km and 10-km test times were 2.3 % and 3.4 %, respectively. The change in running speed of intervals and test runs from T1 to T2 correlated ( $r = 0.75$ ,  $p < 0.001$ ) in both data sets. Thus, the maximal sustainable effort intervals were able to predict 3-km and 10-km running performance and training adaptations with good accuracy, and current results demonstrate the potential usefulness of intervals as part of the monitoring process.

### Corresponding Author:

Olli-Pekka Nuuttila, University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland, opnuuttila@gmail.com

### Affiliations:

Olli-Pekka Nuuttila, University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland  
Pekka Matomäki, University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland  
Heikki Kyröläinen, University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland  
Ari Nummela, Finnish Institute of High Performance Sport KIHU, Physiology, Jyväskylä, Finland

## **Predicting running performance and adaptations from intervals at maximal sustainable effort**

### **ABSTRACT**

This study examined the predictive quality of intervals performed at maximal sustainable effort to predict 3-km and 10-km running times. In addition, changes in interval performance and associated changes in running performance were investigated. Either 6-week (10-km group,  $n = 29$ ) or 2-week (3-km group,  $n = 16$ ) interval training periods were performed by recreational runners. A linear model was created for both groups based on the running speed of the first 6x3-min interval session and the test run of the preceding week (T1). The accuracy of the model was tested with the running speed of the last interval session and the test run after the training period (T2). Pearson correlation was used to analyze relationships between changes in running speeds during the tests and interval sessions. At T2, the mean absolute percentage error of estimate for 3-km and 10-km test times were 2.3 % and 3.4 %, respectively. The change in running speed of intervals and test runs from T1 to T2 correlated ( $r = 0.75$ ,  $p < 0.001$ ) in both data sets. Thus, the maximal sustainable effort intervals were able to predict 3-km and 10-km running performance and training adaptations with good accuracy, and current results demonstrate the potential usefulness of intervals as part of the monitoring process.

**Keywords:** Running, endurance training, interval training, perceived effort

## INTRODUCTION

Distance running consists of a wide spectrum of events from shorter track races (e.g., 3000, 5000, and 10000 m) to road races up to marathons and beyond. Although the duration of such events ranges from < 10 minutes to multiple hours, the physiological determinants of successful performance seem to be surprisingly similar across the distances: Predictors such as peak velocity achieved during the incremental test ( $v_{Peak}$ ), speed at the lactate/ventilatory threshold, and maximal oxygen uptake ( $VO_{2max}$ ) have all correlated significantly with the performance in multiple distances from 3 km to marathon [1, 2, 3, 4]. Although laboratory-derived parameters provide accurate information on specific physiological parameters, their applicability in day-to-day monitoring of training is more challenging. Therefore, field-based submaximal tests [5], training data-derived indexes [6],  $VO_{2max}$  estimations [7], or multivariable models [8] have been proposed to allow estimations of running performance and training adaptations without disturbing the normal training process.

Indirect performance estimations are typically based on the relationship between internal response (heart rate, perceived effort) and external load (speed or power) assessed during submaximal effort [9]. In cross-sectional designs, these types of tests work well, and significant correlations have been found between power or speed at a fixed heart rate (HR) and performance in time-trial-based events [10] or laboratory tests [5]. General assumption in submaximal tests is that decreasing internal load at a certain external load could be translated to improved maximal performance, and indeed, correlations have been found between changes in submaximal performance in the field and maximal performance in the laboratory [5, 6]. However, the HR-based tests also have their limitations. Especially during periods of high training load, HR may act paradoxically making interpreting more challenging and requiring a multitargeted approach to contextualize changes properly [9, 11]. Recently, Sangan et al. [12] introduced a submaximal test which instead of relying on a certain fixed HR or speed was prescribed based on the rating of perceived exertion (RPE). The authors found that the RPE-based test was valid and reliable for monitoring parameters associated with aerobic fitness. Furthermore, Sangan et al. [12] observed that the highest speed of the test (RPE 17/20) had the strongest association with the parameters of the graded exercise test, which is in line with the HR-based tests [5].

Perceived exertion or effort could also be applied in the interval training prescription. More traditionally intervals are prescribed based on a certain speed or HR relative to maximum [13], whereas the “maximal sustainable effort” -method targets the power or speed that the individual estimates to be sustainable through the session [14, 15, 16]. In this approach, the intensity is regulated based on perceptual responses without relying on any predetermined intensity level. Hence, it does not share the same limitations that e.g., the HR-based prescription may have. It has also been suggested that this method would allow each interval session to be an indicator of the current performance level itself [15]. Since high-intensity interval training (HIIT) is an essential part of endurance training [13], it could be useful if performance and adaptations could be monitored reliably alongside the natural training process with maximal sustainable effort intervals.

To the best of our knowledge, no previous studies exist, which have examined the predictive capacity of interval session speeds on distance running performance. Therefore, this study examined the capability of 6x3-min maximal sustainable effort intervals to predict 3-km and

10-km running performance as well as performance changes in these distances followed by a training period.

## **METHODS**

### **Participants**

The study consisted of two separate data sets that were collected during previous intervention studies [16, 17]. In both datasets, participants were recreationally endurance-trained male and female runners (Table 1). All participants who executed analyzed interval sessions appropriately (maximal sustainable effort, speed > 80 % vPeak) and did not have any extensive delays (> 2 weeks) between the last interval session of the training period and the subsequent 3-km or 10-km running tests were involved in the analysis. The study protocol was approved by the Ethics Committee of the University of Jyväskylä.

### **Experimental design**

Data for the studies were extracted from intervention studies [16, 17] that used same kind of 6x3-min interval sessions and executed either a 3-km track running test or a 10-km road running test as a performance outcome test before and after the interval training period. The timing (T1 and T2) of the 6x3-min interval sessions and test runs with respect to the training interventions are presented in Figure 1.

### **Measurements**

#### **6x3-min interval session**

The same 6x3-min interval session was prescribed in both data sets. Instead of HR-based targets, the session was prescribed “at maximal sustainable effort” [14, 15, 16]. Participants were advised to target the highest possible average running speed during the session regardless of HR. In the first session, the participants were given an approximate estimation speed (~3-km running speed or ~ 90 %/vPeak) for helping to adjust the pacing at the beginning of the session. However, they were also advised to regulate their speed based on perceived effort during the session for achieving individually maximal sustainable speed. Intervals were interpreted with 2-min active recovery (walking). Before the intervals, 15-min low-intensity warm-up containing 2-3 ~30 s accelerations were performed for achieving the target speed. Intervals were performed on even surfaces on a road or a running track. From all sessions, the average speed and HR were calculated for each 3-min interval after which the average of six intervals was drawn and used in the further analysis. GPS-based speed and HR data were collected with a Garmin Forerunner 245M watch and an HRM-Tri strap (Garmin Ltd, Schaffhausen, Switzerland) in the 3-km dataset and with a Polar Vantage V2 watch and an H10 strap (Polar Electro Oy, Kempele, Finland) in the 10-km dataset. In addition, the highest HR (HRpeak) achieved during the session was recorded. An example of the running speed and HR during one interval session is demonstrated in Figure 2.

#### **Running tests**

Both test attempts (T1 and T2) were performed at the same time within an individual ( $\pm 2$  h). The 3-km running test was performed on a 200-m indoor track while the 10-km running test was performed outdoors, on a flat asphalt road. Before each test, a similar warm-up as before 6x3-min intervals was executed. Tests were run in small groups (max. 7 people). Time,

average running speed, average HR, and peak HR were analyzed from all tests. Incremental treadmill protocol is presented in more detail elsewhere [16, 17]. Parameters that were used in the current analyses involved HR<sub>peak</sub>, submaximal VO<sub>2</sub> at 10 km/h, VO<sub>2max</sub>, speed at the first (vLT1) and the second (vLT2) lactate thresholds and peak speed (vPeak) during the test. In the 3-km intervention, the treadmill test was performed only before the short preparatory period (~ 3 weeks before the 3-km test at T1), while in the 10-km intervention the treadmill test was performed 2-4 days before the 10-km running test at all time points.

### Statistical analysis

Results are presented as mean  $\pm$  SD. The normality of the data was assessed with the Shapiro-Wilk test. Coefficient of determination (R<sup>2</sup>) was analyzed between running speed in the running tests and average running speed of 6x3-min intervals as well as incremental treadmill test variables at T1. Reported 95 % confidence interval (CI) for correlation coefficients were calculated by means of Fisher z-transformation. The estimation models for 3 km and 10 km performance were created based on the relationships between the running speeds of the first 6x3-min intervals and the test runs at T1. The same model was tested for the T2 interval session, and the estimated running speed was transformed into the estimated running time which was compared to the actual test result. The accuracy of the models was analyzed with the standard error of estimate (SEE), mean absolute percentage error (MAPE), and Bland-Altman Limits of Agreements. Differences within groups (T1 vs. T2, estimated vs. measured performance, 6x3-min vs. 3-km or 10-km) were analyzed with paired samples t-test. Pearson correlation coefficient was used to analyze relationships between relative changes in the running speed of 6x3-min intervals and running tests from T1 to T2. Analyses were performed with Microsoft Excel 2016 (Microsoft Corporation, WA) and IBM SPSS Statistics version 28 programs (SPSS Inc, Chicago, IL).

### RESULTS

Descriptive characteristics of 3-km and 10-km tests at T1 as well as the details of the first 6x3-min interval sessions are presented in Table 2. Mean running speed during the 6x3-min intervals was 101.1  $\pm$  2.7 % of 3-km speed ( $p = 0.17$ ) and 108.9  $\pm$  4.4% of 10-km speed ( $p < 0.001$ ). HR<sub>avg</sub> and HR<sub>peak</sub> were higher ( $p < 0.001$ ) in both test conditions compared to HR achieved during the interval sessions.

As presented in table 3, the coefficient of determination of vPeak for running performance (km/h) was 0.92 (CI 0.79; 0.97) in the 3-km, 0.94 (CI 0.88; 0.97) in the 10-km, and 0.92 (CI 0.85; 0.95) in the 6x3-min intervals. In turn, the submaximal running economy had the lowest coefficient of determination for test or interval performance among the treadmill test parameters.

Based on the linear model between the running speed of the 6x3-min intervals and the performance in the 3-km and 10-km tests at T1 (Figure 3), an equation was created to predict performance at the T2 tests. At T2 the coefficient of determination for the model was 0.95 in 3 km and 0.92 in 10 km.

In 3 km, measured and estimated times at T2 were 12:06  $\pm$  1:29 min:s and 12:08  $\pm$  1:27 min:s ( $p = 0.39$ ), while in 10 km, measured and estimated times at T2 were 44:03  $\pm$  6:13 min:s and 43:55  $\pm$  6:01 min:s ( $p = 0.41$ ) respectively. SEE for the 3-km and 10-km estimations was 0:23

min:s and 1:50 min:s, while MAPE was 2.3% and 3.4%, respectively. Bland-Altman plot (Figure 4) illustrates the differences and limits of agreements for both estimates at T2.

A significant increment was observed in the running speed of the 6x3-min intervals from T1 to T2 in 3-km ( $2.2 \pm 3.1$  %,  $p = 0.019$ ) and 10-km ( $3.4 \pm 5.1$  %,  $p = 0.001$ ) datasets. In addition, running speeds in the 3-km ( $1.6 \pm 1.8$  %,  $p = 0.004$ ) and 10-km ( $3.2 \pm 2.8$  %,  $p < 0.001$ ) tests increased and the relative changes correlated significantly with respective changes in interval sessions (Figure 5).

## DISCUSSION

There were two key findings of the study: Firstly, maximal sustainable effort by 6x3-min intervals were able to predict 3-km and 10-km running performance with similar or better accuracy compared to laboratory-derived markers. Secondly, significant correlations were found between the relative changes in interval and distance running performance. Current results demonstrated the potential of these sessions in the estimation of the appropriate running speed for 3-km and 10-km distances as well as their usefulness in the monitoring of endurance training adaptations.

### Estimation of distance running performance

Predictive factors of distance running performance have been of interest for a long time and in multiple studies. It is already known that performance at a certain distance can be predicted accurately based on performance on other distances [1], and multiple formulas exist that can predict race time with a decent accuracy based on the assumption of inter-reliance between different distances [18, 19, 20]. In congruence with the presented results vPeak has probably been the best or most consistently found laboratory-based predictor of distance running performance. High correlations ( $> 0.85$ ) have been found for distances ranging from 1500 m [3] to a marathon [1, 3]. Accuracy of estimate can be further improved, when additional variables such as lactate threshold and running economy are included in multiple regression models [21]. The coefficient of determination for investigated interval sessions ( $R^2$  for 3 km 0.96, and  $R^2$  for 10 km 0.93) was similar or even higher compared to previously reported laboratory-derived predictors for 3 km [2, 4, 22] or 10 km [1, 3, 23], demonstrating the significant association between interval and distance running performance, even in field conditions.

Regarding the actual estimation (time) of running performance, several studies have introduced models aiming to predict finishing times based on single or multiple variables. For 3 km, Slattery et al. [24] proposed a vPeak-based model which induced SEE of 24 s, and when velocity at the lactate threshold and peak blood lactate values were added to the model, SEE decreased to 15 s. Altini and Amft, [8] used multiple variables (performance, training, anthropometrics, resting physiology) for their estimation of 10-km time and reported MAPE of 4.0 % and root mean square error of 2.7 min for the most accurate model. Abad et al. [25] in turn, created a model for 10 km that used either vPeak (SEE = 1.9 min) or a combination of vPeak and submaximal running economy (SEE = 1.5 min). Current SEE values of 23 s for 3 km and 1.8 min for 10 km are well in line with previous models and both could be regarded as accurate estimations for the current group of recreational runners. When considering the predictive accuracy of models in general, it is important to acknowledge the day-to-day

variation in the distance running performance which has been reported to vary between 1.2-2.0 % in well-trained athletes [26].

### **Monitoring of training adaptation**

Although clear correlations could be found between laboratory test results and distance running performance in cross-sectional designs, changes in these markers are not always as conclusive. For example, the change in  $\text{VO}_{2\text{max}}$  will not always correlate with the change in distance running performance either in recreational [27, 28] or well-trained runners [28]. Studies examining field-based tests have mostly analyzed changes in laboratory performance (e.g.  $\text{VO}_{2\text{max}}$  or  $v\text{Peak}$ ) [5, 6], while only a few studies have examined explanatory factors of improved distance running (competition) performance. Paavolainen et al. [29] found significant correlations between the change in 5-km running performance and improvement of maximal treadmill performance ( $r = 0.63$ ), running economy ( $r = 0.55$ ), and anaerobic MART test performance ( $r = 0.55$ ) in well-trained athletes. In turn, da Silva et al. [30] found a similar correlation ( $r = -0.65$ ) between the change in  $v\text{Peak}$  and time to finish 5 km in untrained women. Smith et al. [31] found lower correlations for the change in  $v\text{VO}_{2\text{max}}$  ( $r = 0.40$ ) and 3-km performance, while the change in running economy ( $r = 0.76$ ) and  $\text{VO}_{2\text{max}}$  ( $r = 0.78$ ) were better aligned with improved 3-km time. Compared to these laboratory tests, even higher correlation coefficients ( $r = 0.75$ ) were present in our study. Therefore, maximal sustainable interval performance shares a strong relationship with the current competition performance, supporting suggestions by Rønnestad et al. [15].

### **The nature of the maximal sustainable effort interval prescription**

Based on the running speed and  $\text{HR}_{\text{peak}}$  achieved during the interval session, the present prescription was performed close to the individuals' maximum aerobic performance ( $v\text{VO}_{2\text{max}}$ ). Although these kinds of intervals are performed at the "maximal sustainable effort", session RPE values of  $\sim 8/10$  have been reported with current 6x3-min intervals [16] and quite similar 4x4-min intervals [32]. When utilizing the effort-based approach, it seems that shorter intervals lead to higher RPE and session RPE values compared to longer intervals [32]. Furthermore, an interval prescription affects significantly physiological aspects such as blood lactate and HR during the session [32]. Future studies could investigate how the manipulation of duration or work:recovery -ratio would affect the prediction accuracy. It can be speculated that the interval prescription leading closest to the expected speed of the target distance would provide the most accurate prediction.

It has been suggested that pacing in distance running is strongly regulated by perceived exertion [33]. The mismatch between expected and actual perceived exertion leads to an adjustment of pace to reach the desirable exertion [33]. While intervals are often prescribed at a certain fixed HR or speed (e.g. x% of maximal or threshold), maximal sustainable effort intervals require exactly the same evaluation between the expected and actual perceived exertion as distance running races. As Seiler and Sylta [32] discussed, there is still some debate whether perceived effort is centrally driven or modulated directly by afferent feedback from peripheral sensors. In line with Marcora [34], they concluded that RPE could be a slightly different feature of fatigue from physiological parameters such as blood lactate or HR. Therefore, it is tempting to speculate that effort-based intervals could provide some additional information on performance compared to predefined interval prescription, and this could also be a reason for the strong associations found in the present study. Whether a



similar relationship exists with the submaximal RPE-based tests [12], and whether accurate performance predictions require maximal effort, are interesting questions raising from the current findings.

### **Limitations**

There are also some limitations to acknowledge when interpreting the results and applying them into practice. The data was collected along with two training interventions, and the design did not primarily target the analysis of this study. The running tests were performed on an indoor track (3 km) and on an asphalt road (10 km), while the interval sessions were performed outdoors. In outdoor sessions, environmental factors could not be controlled with similar precision as in the laboratory. Therefore, current formulas for predicting 3-km and 10-km running performance might be less accurate, if either the tests or the intervals were performed in other running environments. Intervention periods for the 3-km and 10-km datasets were not identical in length or design, thus certain aspects such as accumulated fatigue may have had a different impact on the results. Further studies are needed to confirm and expand current findings to different disciplines (e.g., cycling), interval modifications, and populations (untrained, well-trained) – especially in competitive athletes requiring small margin of error.

### **Conclusions**

In conclusion, a 6x3-min interval session performed at maximal sustainable effort was able to predict 3-km and 10-km distance running performance with good accuracy in recreational runners. Furthermore, changes in interval running speed were sensible to changes in distance running performance, thus supporting the usefulness of maximal sustainable intervals in monitoring and predicting adaptations to endurance training.

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## FIGURE LEGENDS

Figure 1. Timing of the tests and 6x3-min interval sessions in groups performing 3-km or 10-km running tests before (T1) and after (T2) after the training periods.

Figure 2. An example of running speed and heart rate (HR) in relation to the maximum in the 6x3-min interval session.

Figure 3. Linear models for 3 km (A) and 10 km (B) were created based on the interval session and test run at T1.

Figure 4. Bland-Altman Limits of Agreement (LoA) for the estimated and measured running performance at T2 in 3 km (A) and 10 km (B).

Figure 5. Correlations between the relative changes in the running speed of the 6x3-min intervals and test runs from T1 to T2.

## TABLE LEGENDS

Table 1. Mean  $\pm$  standard deviation (SD) baseline characteristics of the participants that performed 3-km or 10-km running tests. Training volume was analyzed from the preparatory period preceding the training intervention.

Table 2. Mean  $\pm$  SD running test and interval session results at T1 in the groups performing either 3-km or 10-km running test. The interval session was similar in both groups.

Table 3. The coefficient of determination ( $R^2$ ) for the running speed in the 3-km test, 10-km test and 6x3-min interval session at T1.

Table 1. Mean  $\pm$  standard deviation (SD) baseline characteristics of the participants that performed 3-km or 10-km running tests. Training volume was analyzed from the preparatory period preceding the training intervention.

	3 km (n = 16)	10 km (n = 29)
Sex (Males/Females)	10/6	16/13
Age (y)	34 $\pm$ 7	36 $\pm$ 7
Height (cm)	173 $\pm$ 9	174 $\pm$ 8
Body mass (kg)	73 $\pm$ 14	71 $\pm$ 13
VO <sub>2max</sub> (ml/kg/min)	51 $\pm$ 7	48 $\pm$ 6
Training (h/week)	5.7 $\pm$ 1.7	4.3 $\pm$ 0.9

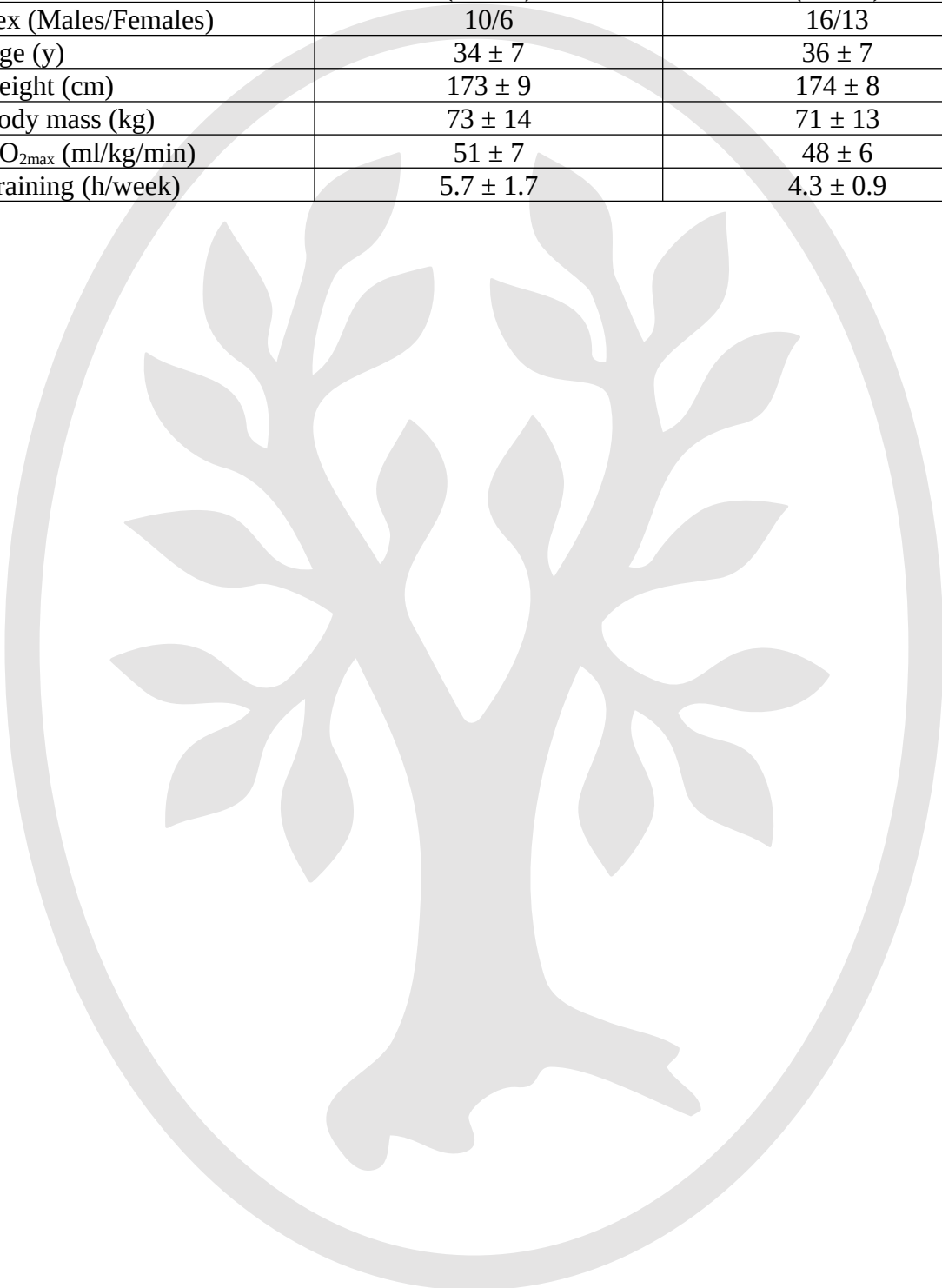


Table 2. Mean  $\pm$  SD running test and interval session results at T1 in the groups performing either 3-km or 10-km running test. The interval session was similar in both groups.

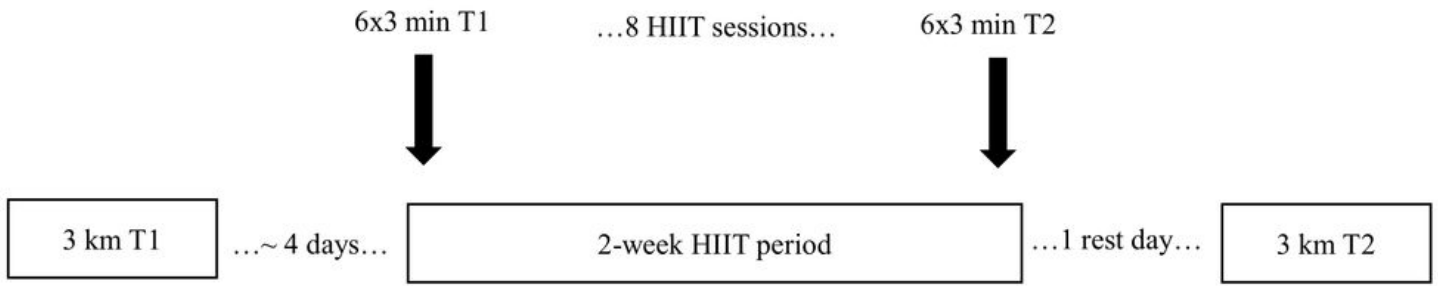
	3 km (n = 16)	10 km (n = 29)
<b>Running test results</b>		
Time (min:s)	12:18 $\pm$ 1:29	45:26 $\pm$ 6:13
Running speed (km/h)	14.8 $\pm$ 1.7	13.4 $\pm$ 1.8
Running speed (%/vPeak)	89.1 $\pm$ 3.0	81.7 $\pm$ 2.9
HRavg (%/max)	94.1 $\pm$ 2.5	93.2 $\pm$ 1.7
HRpeak (%/max)	99.1 $\pm$ 2.2	98.7 $\pm$ 1.8
<b>6x3 min interval results</b>		
Running speed (km/h)	14.8 $\pm$ 1.7	14.6 $\pm$ 1.6
Running speed (%/vPeak)	90.0 $\pm$ 2.3	89.0 $\pm$ 3.2
HRavg (%/max)	90.5 $\pm$ 1.9	88.9 $\pm$ 2.7
HRpeak (%/max)	96.4 $\pm$ 2.0	96.4 $\pm$ 2.7
HRavg, average heart rate; HRpeak, peak heart rate; vPeak, peak treadmill test velocity.		

Table 3. The coefficient of determination ( $R^2$ ) for the running speed in the 3-km test, 10-km test and 6x3-min interval session at T1.

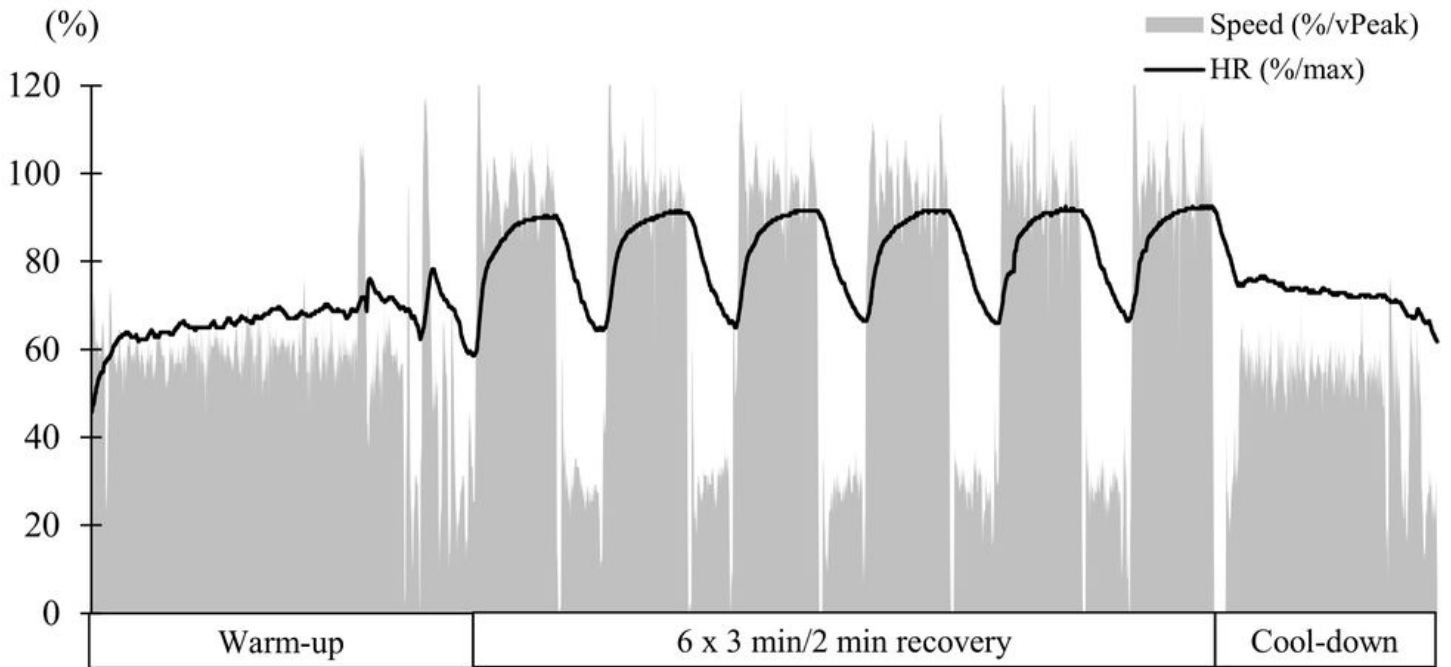
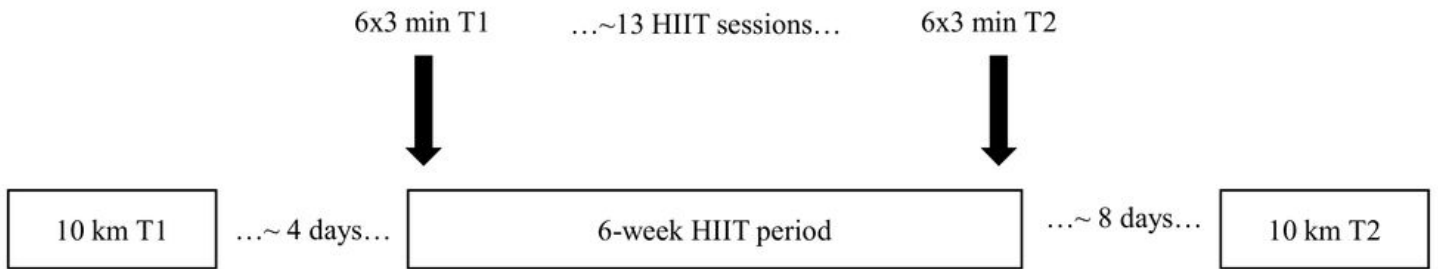
	3 km (n = 16)	10 km (n = 29)	6x3 min (n = 45)
vPeak (km/h)	0.92	0.94	0.92
vLT2 (km/h)	0.82	0.89	0.79
vLT1 (km/h)	0.55	0.75	0.63
VO <sub>2max</sub> (ml/kg/min)	0.84	0.78	0.76
VO <sub>2max</sub> (l/min)	0.47	0.46	0.54
VO <sub>2sub</sub> (ml/kg/min)	0.08	0.03	0.00

vPeak, peak treadmill test velocity; vLT2, the velocity at the second lactate threshold; vLT1, the velocity at the first lactate threshold; VO<sub>2max</sub>, maximal oxygen uptake; VO<sub>2sub</sub>, oxygen consumption at 10 km/h running speed.

**A) Timing of tests and interval sessions in the 3 km group**



**B) Timing of tests and interval sessions in the 10 km group**



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