Relationship between perceived exertion during exercise and subsequent recovery measurements

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ABSTRACT: The return towards resting homeostasis in the post-exercise period has the potential to represent the internal training load of the preceding exercise bout. However, the relative potential of metabolic and autonomic recovery measurements in this role has not previously been established. Therefore the aim of this study was to investigate which of 4 recovery measurements was most closely associated with Borg's Rating of Perceived Exertion (RPE), a measurement widely acknowledged as an integrated measurement of the homeostatic stress of an exercise bout. A heterogeneous group of trained and untrained participants (n = 36) completed a bout of exercise on the treadmill (3 km at 70% of maximal oxygen uptake) followed by 1 hour of controlled recovery. Expired respiratory gases and heart rate (HR) were measured throughout the exercise and recovery phases of the trial with recovery measurements used to calculate the magnitude of excess post-exercise oxygen consumption ($EPOC_{MAG}$), the time constant of the EPOC curve ($EPOC\tau$), 1 min heart rate recovery (HRR_{60s}) and the time constant of the HR recovery curve ($HRR\tau$) for each participant. RPE taken in the last minute of exercise was significantly associated with HRR_{60s} (r=-0.69), $EPOC\tau$ (r=0.52) and $HRR\tau$ (r=0.43) but not with $EPOC_{MAG}$. This finding suggests that, of the 4 recovery measurements under investigation, HRR_{60s} shows modest potential to represent inter-individual variation in the homeostatic stress of a standardized exercise bout, in a group with a range of fitness levels.

INTRODUCTION

The homeostatic stress or "internal training load" associated with an exercise bout has important implications for the adaptive stimulus incurred, the appropriate timing and load of subsequent exercise bouts and the extent to which the responses of individuals performing an "equivalent" exercise bout can be compared. Training load is determined by the interaction of exercise intensity and duration and is intuitively associated with a variety of physiological and metabolic changes. Nevertheless, it is challenging to identify a single exercise measurement to represent the integrated effect of these homeostatic disturbances and so quantify the training load of an exercise bout [1].

Rather than focusing on measurements during the exercise itself, an alternative approach to quantifying training load is to focus on the recovery towards resting homeostasis after the termination of the exercise [2–4]. The rationale for this approach is that the homeostatic stress of an exercise bout would be expected to have a large influence on the time taken to reverse the associated exercise re-sponses. This rationale is supported by a number of studies in which measures of dynamic autonomic or metabolic recovery were shown to be sensitive to changes in exercise intensity and/or duration [2, 3, 5–9].

It follows that both autonomic and metabolic recovery measurements warrant further investigation as possible measures of training load. For example, it is rare for autonomic and metabolic recovery measurements to be compared within the same study [4] and the relative sensitivity of conventional measures of autonomic recovery (e.g. heart rate recovery) and metabolic recovery (e.g. post-exercise oxygen consumption) to inter- or intra- individual variation in homeostatic stress has not been clearly established.

There is at present no gold standard of training load against which these recovery measurements can be compared [1]. However, for the current cross-sectional study we chose to investigate which of 2 conventional means of calculating post-exercise oxygen consumption and 2 conventional means of calculating heart rate recovery was

most closely associated with Borg's Rating of Perceived Exertion (RPE). Although RPE may be influenced by psychological factors [10, 11], it has been strongly correlated with heart rate (HR) and blood lactate measurements in a variety of populations [12] and is widely recognized as an integrated measure of the homeostatic disturbance during exercise [13].

Therefore, it was anticipated that the recovery measurement most closely associated with RPE may have the highest relative potential to represent the homeostatic stress or training load of the preceding exercise bout. The 4 recovery measurements under investigation were the magnitude of excess post-exercise oxygen consumption ($EPOC_{MAG}$), the time constant of the oxygen consumption recovery curve ($EPOC\tau$), 1 min heart rate recovery (HRR_{60s}) and the time constant of the heart rate recovery curve ($HRR\tau$).

MATERIALS AND METHODS

Participants. A heterogeneous group of 46 untrained individuals and trained runners were recruited for the study. Untrained individuals were not engaged in any regular exercise training whereas the trained individuals had accumulated a training distance of ≥ 20 km per week most weeks for the past 3 months, by self-report. All participants were required to be between the ages of 18 and 45 years, non-smokers, able to answer "no" to all the questions in a Physical Activity Readiness Questionnaire (PAR-Q) [14] and have a body mass index (BMI) < 30 kg·m^{-2}. The study was approved by the university Human Research Ethics Committee and was conducted in accordance with the Declaration of Helsinki [15]. All participants signed an informed consent form prior to taking part in the study.

Experimental overview
Participants visited the laboratory on 2 occasions, 3-7 days apart. Visit 1 was comprised of anthropometric measurements and a maximal treadmill test and visit 2 was comprised of a submaximal treadmill exercise followed by a period of controlled recovery. All participants were asked to refrain from any strenuous exercise the day before each session and not to exercise prior to the laboratory visit on the day of testing.

Visit 1: Anthropometry and maximal treadmill test
Participant's body mass and height were determined using a calibrated scale (Detecto BW-150, Webb City, USA) and stadiometer (Detecto BW-150, Webb City, USA), respectively. In addition, each participant's body fat percentage was determined using Dual-energy X-ray Absorptiometry (DXA) (Hologic Discovery-W, software version 12.1, Hologic, Bedford, MA, USA). Body mass was re-measured at the start of the 2nd laboratory visit.

All participants completed a self-paced treadmill familiarization and warm-up followed by the Bruce protocol [16] maximal treadmill test. The test began from the 2nd stage of the protocol (4.7 km·h^{-1}, 12% gradient) and continued until volitional exhaustion. HR (Suunto t6, Suunto Oy, Vantaa, Finland) and breath-by-breath respira-

tory gases (Jaeger Oxycon Pro, Hoechberg, Germany) were measured continuously during the test. VO$_2$max was defined as the highest 15 s average oxygen uptake (VO$_2$) measured during the test, as recommended by Macfarlane [17], while HRmax was defined as the highest 2 s average HR during the test. The Oxycon Pro, which has been previously validated against the Douglas Bag system [18], was calibrated immediately before each laboratory visit using a 3 L syringe (SensorMedics$^{®}$, Milan, Italy) and a reference gas of known composition (16% oxygen, 5% carbon dioxide, balance nitrogen).

Visit 2: Submaximal exercise and recovery trial
Participants were asked to refrain from eating and to drink only water for at least 2 hours and compliance with the 2 hour fast was verbally confirmed with each participant upon arrival at the laboratory.

For pre-exercise VO$_2$ measurements, participants lay supine in a darkened room and were asked to remain quiet and still until VO$_2$ had stabilized and 10-15 min of stable VO$_2$ data had been collected using a breath-by-breath gas analysis system (Quark CPET, Cosmed, Rome, Italy). This method of obtaining a baseline measurement is similar to those reported elsewhere [19–21]. The gas analyzers and flow metre of the gas analysis system were calibrated shortly before the start of each trial according to the manufacturer's instructions.

Submaximal treadmill exercise
The submaximal bout consisted of 3 km of treadmill exercise at 70% VO$_2$max and was intended to be similar to a typical training session in the early stages of a 12 week training program for novice runners on which our laboratory was also conducting research. Treadmill speed for the exercise was inferred based on each participant's performance in the maximal treadmill test. Breath-by-breath respiratory gases (Jaeger Oxycon Pro, Hoechberg, Germany) and HR were measured continuously throughout the treadmill exercise. If necessary, the treadmill gradient was adjusted within the first 2-3 min of the exercise bout to elicit a VO$_2$ as close as possible to the target VO$_2$ (70% of VO$_2$max). Shortly before the 3 km exercise was complete, participants were asked to indicate an RPE on Borg's 6-20 RPE scale [22]. This scale had been fully explained to each participant at the start of the trial.

Immediately upon completing the 3 km exercise, the treadmill was stopped and the participant stood as still as possible for the first 5 min post-exercise to obtain a continuous recording of respiratory gases and HR for the steepest portion of the recovery curve. The Oxycon mask was then removed and the participant sat in a chair and was wheeled to a bed about 40 m away. The participant lay down and the recovery measurements continued using the Cosmed Quark until a total of 60 min of recovery had been measured.

Data analysis
For the baseline, exercise and recovery components of the trial, respiratory gases were expressed in 15 s averages and HR was expressed in 2 s averages.

RPE and recovery measurements

Pre-exercise VO_2 measurements were obtained by averaging the last ± 10 min of the stable, supine rest data. For the exercise bout, the first 3 min of data were discarded and the remainder averaged to obtain the steady-state VO_2, respiratory exchange ratio (RER) and HR for the treadmill exercise. The energy expenditure (EE) associated with the 3 km exercise was calculated according to standard caloric equivalents for oxygen at different RER values [23]. The first 3 min of exercise were included when calculating EE, although it is acknowledged that RER does not reliably reflect caloric expenditure until a steady-state is acquired. To ensure that participants did indeed complete the exercise at approximately 70% of VO_2max, the average VO_2 during the exercise bout was required to be within 2 ml·kg^{-1}·min^{-1} of the target absolute VO_2 and/or within 5% of the 70% VO_2max target to avoid exclusion from the subsequent analysis.

HRR_{60s} was calculated as the difference between the end of exercise HR (defined as the average of the last 16 s of the exercise period) and the 1 min recovery HR (defined as the average of the last 16 s of the first recovery minute) as described elsewhere [24]. The start of recovery was timed from the point at which the participant was standing upright on the stationery treadmill belt. To calculate HRR , a one phase decay curve was fitted to the HR data from immediately after the termination of exercise until the 60th minute of recovery using Graphpad Prism (GraphPad Prism version 5.00 for Windows, GraphPad Software, San Diego California USA). HRRτ was defined as the time constant of the heart rate recovery curve. A one phase decay has been found to be suitable for modelling heart rate recovery from submaximal exercise intensities [25].

Recovery VO_2 (ml·min^{-1}) was plotted on the same set of axes for 0-5 min (Oxycon data) and 8-60 min (Cosmed Quark data), respectively. The start of the recovery curve was made equal to the average VO_2 of the last 3 min of exercise and a one phase decay was used to form a continuous recovery curve from the two data sets (GraphPad Prism version 5, GraphPad Software, San Diego California USA). It has previously been shown that recovery VO_2 kinetics are adequately characterized by a mono-exponential function following steady-state exercise at "moderate" and "heavy" exercise intensities [26, 27]. EPOCτ was defined as the time constant of the one phase decay. $EPOC_{MAG}$ was calculated as the area under the one phase decay curve with the base of the curve adjusted to each participant's pre-exercise VO_2.

Statistical analysis

Data is presented as mean ± standard deviation (SD) along with the coefficient of variation (CV). CV's were calculated as the (standard deviation of the group/group mean)*100. All data was tested for normal distribution using a D'Agostino and Pearson normality test. Normally-distributed data was investigated using parametric analyses and non-normally distributed data using non-parametric analyses. For example, participant characteristics, exercise and recovery outcomes were compared between the trained and untrained participants using an unpaired t-test or Mann Whitney test, as appropriate and associations between RPE and each recovery variable was investigated using a Pearson's correlation or Spearman's correlation, as appropriate. Correlations between RPE and each recovery variable were performed for all participants as well as for trained participants only and untrained participants only and each correlation coefficient is presented with 95% confidence intervals (C.I.). The magnitude of correlation coefficients was interpreted as ≤ 0.1 = trivial,

TABLE 1. Participant characteristics.

	Untrained participants n = 11 (2M, 9F) Mean ± SD (Range)	CV	Trained participants n = 25 (12M, 13F) Mean ± SD (Range)	CV	All participants n = 36 (14M, 22F) Mean ± SD (Range)	CV
Age (years)	31 ± 4 (25-40)	14	31 ± 5 (23-44)	17	31 ± 5 (23-44)	16
Height (cm)	168 ± 6 (159-182)	3	175 ± 10* (161-196)	6	173 ± 9 (159-196)	5
Body Mass (kg)	74.8 ± 6.8 (62.9-85.0)	9	68.8 ± 12.1 (49.1-99.2)	18	70.6 ± 11.0 (49.1-99.2)	16
Body Mass Index (kg·m^{-2})	26.5 ± 2.7 (21.1-29.6)	10	22.5 ± 2.8** (17.9-29.5)	12	23.7 ± 3.3 (17.9-29.6)	14
Body fat (%)	36.5 ± 7.5 (19.0-45.4)	21	20.0 ± 7.4*** (9.8-37.4)	37	25.0 ± 10.7 (9.8-45.4)	43
Training volume (km·wk^{-1})	0 ± 0 (0-0)	0	46 ± 26*** (20-120)	55	32 ± 30 (0-120)	93
VO_2max (ml·kg^{-1}·min^{-1})	32.6 ± 6.4 (25.4-45.8)	20	55.9 ± 7.6*** (39.3-66.9)	14	48.8 ± 13.0 (25.4-66.9)	27
Bruce protocol time (min)	6.1 ± 1.4 (4.0-9.0)	23	12.1 ± 2.3*** (7.8-16.4)	19	10.3 ± 3.4 (4.0-16.4)	34

Note: M = male participants F = female participants CV = coefficient of variation. All coefficient of variation values are reported as a percentage.
*Significant difference between untrained participants and trained participants *p < 0.05, **p<0.01, ***p<0.0001.

> 0.1 to ≤ 0.3 = small, > 0.3 to ≤ 0.5 = moderate, > 0.5 to ≤ 0.7 = large, > 0.7 to ≤ 0.9 = very large and > 0.9 = near perfect [28]. All of the afore-mentioned statistical analyses were conducted using Graphpad Prism 5 (GraphPad Prism 5, GraphPad Software, San Diego California USA) with statistical significance accepted as $p < 0.05$.

RESULTS

Participant characteristics. Although 46 participants completed the laboratory procedures, some were excluded from further analysis for disclosing ill-health during testing (1 participant) and falling outside of the target intensity of 70% VO_{2max} during the submaximal tread-mill exercise (9 participants) (*see Materials and Methods*). The re-maining 36 participants included a mixture of trained (n = 25) and untrained individuals (n = 11) and showed large inter-individual variation in body fat %, training volume, VO_2max and Bruce protocol time. These and other participant characteristics appear in Table 1.

Submaximal exercise and recovery measurements

The required VO_2 for the 3 km exercise bout was achieved using a combination of speed (8.2 ± 1.2 km·h^{-1}) and gradient (4.7 ± 2.6%)
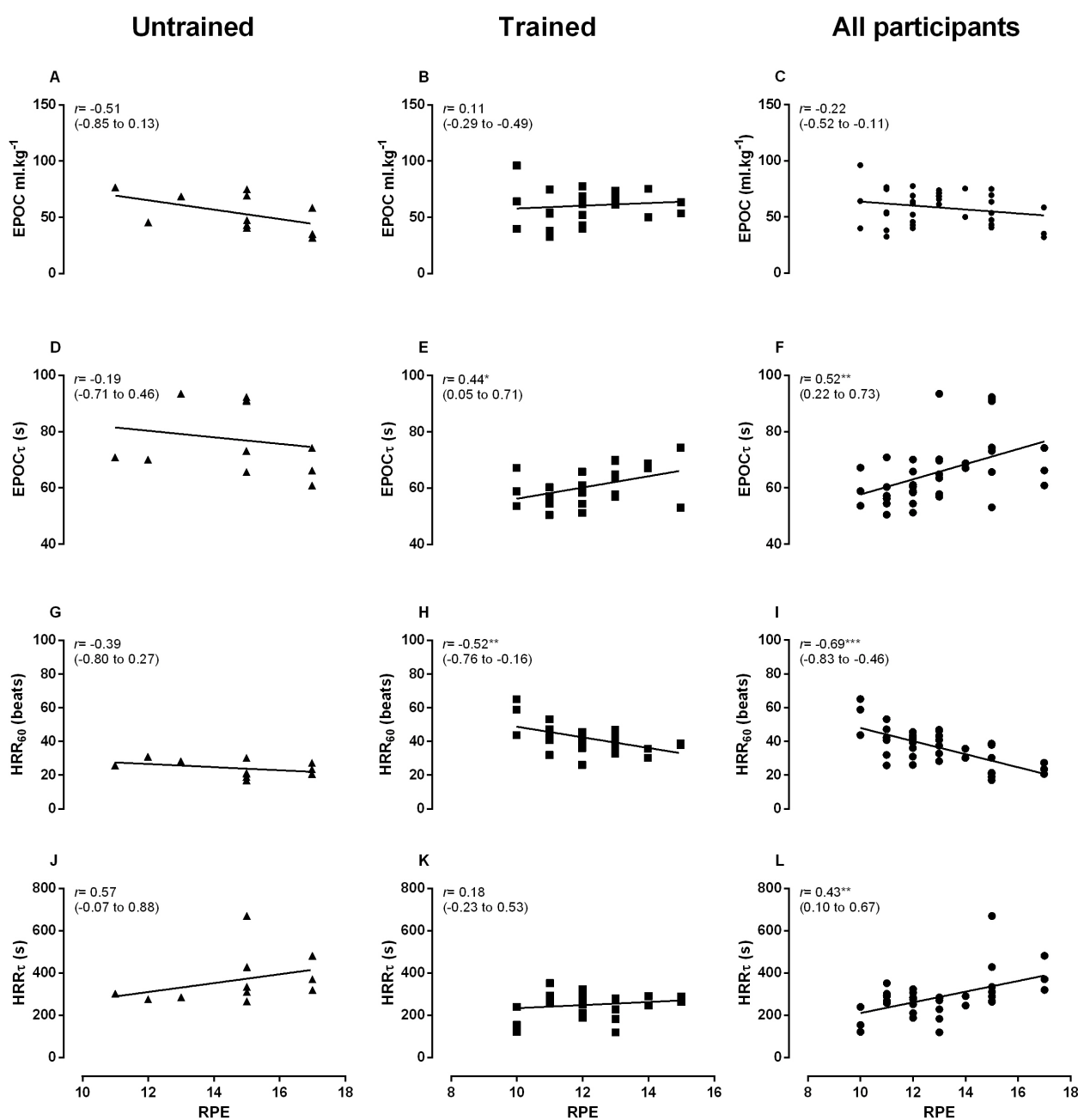

FIG. 1. Correlations between RPE and recovery measurements in Untrained participants only, Trained participants only and All participants. Correlation coefficients are presented with 95% confidence intervals. *$p<0.05$, **$p<0.01$, ***$p<0.0001$.

and resulted in an average exercise intensity of 70.3 ± 2.3 %VO$_2$max. Although participants completed the exercise bout at the same percentage VO$_2$max, there was noticeable individual variation in the duration and energetic cost of the exercise as well as in HR and RPE responses (Table 2). In a similar way, there was large individual variation in all 4 recovery measurements (Table 2).

Relationship between RPE and recovery measurements

Relationships between RPE and recovery measurements for untrained participants only, trained participants only and all participants are presented in Fig 1. There were no significant associations between RPE and recovery measurements among the untrained participants. However, RPE showed *moderate*, significant associations with EPOCτ ($r = 0.44$, 95% C.I. 0.05 to 0.71, $p=0.03$)(Fig 1E) and HRR$_{60s}$ ($r = -0.52$, 95% C.I. -0.76 to -0.16, $p = 0.007$)(Fig 1H) among the trained participants. Among all participants, RPE showed *moderate*, significant associations with EPOCτ ($r = 0.52$, 95% C.I. 0.22 to 0.73, $p = 0.001$)(Fig 1F), HRR$_{60s}$ ($r = -0.69$, 95% C.I. -0.83 to -0.46, $p < 0.0001$)(Fig 1I) and HRRτ ($r = 0.43$, 95% C.I. 0.10 to 0.67, $p = 0.009$)(Fig 1L).

DISCUSSION

The main finding of the study was that, of the 4 recovery measurements under investigation, HRR$_{60s}$ was most closely associated with RPE following a 3 km exercise bout at 70% VO$_2$max.

Variation in RPE was able to explain 48% of the variation in HRR$_{60s}$ with lower RPE associated with faster recovery. This suggests that HRR$_{60s}$ shows modest potential to represent inter-individual variation in the homeostatic stress of a standardized exercise bout, among individuals with a wide range of fitness levels. Conversely, HRR$_{60s}$ had less variation in common with RPE when training status was less heterogeneous, explaining only 27% of the variation in

RPE among trained participants and 15% of variation among the untrained participants.

To the best of our knowledge, the current study was the first to investigate the association between RPE and measures of autonomic recovery and RPE and measures of metabolic recovery within the same study. However, the current findings are in keeping with previous reports of a significant association between HRR$_{60s}$ and measures of homeostatic stress. For example, Buchheit *et al.* reported significant correlations between blood pH and HRR$_{60s}$ ($r = 0.62$) and blood lactate and HRR$_{60s}$ ($r = -0.67$) during repeated sprint exercise [29]. These correlations were observed in a heterogeneous group of children, adolescents and adults [29]. In a different study, Buchheit,*et al.* reported a significant association between RPE and HRR$_{60s}$ ($r = -0.33$) in moderately trained men after 5 min of running at 60 ± 6 %VO$_2$max [30]. When considered together, the current findings and those of Buchheit *et al.* [29, 30] suggest that the association between RPE and HRR is stronger amongst individuals with a range of fitness levels than among individuals with similar fitness levels. However, it is also likely that the association between RPE and HRR increases with increased exercise intensity and the relative contribution of these influences is not clear.

The current finding of significant associations between RPE and HRR could also be regarded as compatible with significant associations between HRR and physical activity levels reported previously [31, 32]. For example, Lee and Mendoza found a significant association between HRR$_{60s}$ and a questionnaire-based physical activity in a (relatively heterogeneous) group of well-trained athletes ($r = -0.67$) [31] and Buchheit and Gindre found a significant association between HRRτ and questionnaire-based physical activity levels among individuals with a range of fitness levels ($r=0.55$) [32]. In a heterogeneous participant group, physical activity levels may serve as a proxy for an individual's level of training adaptation.

TABLE 2. Exercise and recovery measurements associated with the submaximal treadmill protocol.

	Untrained participants			Trained participants			All participants		
	n = 11 (2M, 9F)			n = 25 (12M, 13F)			n = 36 (14M, 22F)		
	Mean ±SD	Range	CV	Mean ±SD	Range	CV	Mean ±SD	Range	CV
%VO$_2$max (%)	71.7 ±2.8	(65.4-74.5)	4	69.7 ±1.8*	(66.4-72.9)	3	70.3 ±2.3	(65.4-74.5)	3
Duration (min)	27.4 ±2.5	(22.5-30.0)	9	20.4 ±1.5***	(17.8-24.0)	8	22.6 ±3.7	(17.8-30.0)	17
EE (kcal)	179.9 ±27.1	(137.5-228.9)	15	209.5 ±49.6	(139.9-344.3)	24	200.4 ±45.7	(137.5-344.3)	23
RER	0.94 ±0.01	(0.79-1.00)	8	0.92 ±0.05	(0.85-1.02)	6	0.92 ±0.06	(0.79-1.02)	6
HR (bpm)	167 ±18	(131-188)	11	150 ±10**	(131-174)	7	155 ±15	(131-188)	10
%HRmax (%)	86.8 ±6.4	(73.3-92.5)	7	81.5 ±5.0**	(72.9-92.3)	6	83.1 ±5.9	(72.9-92.5)	7
RPE (6-20)	14.7 ±2.0	(11.0-17.0)	14	12.2 ±1.4**	(10.0-15.0)	12	13.0 ±2.0	(10.0-17.0)	15
EPOC$_{MAG}$ (ml·kg^{-1})	54 ±16	(32-77)	30	61 ±15	(33-96)	25	59 ±16	(32-96)	26
EPOCτ (s)	77 ±12	(61-94)	16	61 ±7***	(51-74)	11	66 ±12	(51-94)	17
HRR$_{60s}$ (beats)	24 ±5	(17.0-31.0)	20	42 ±9***	(26-65)	20	37 ±11	(17-65)	31
HRRτ (s)	368 ±120	(266-670)	33	250 ±59**	(119-352)	24	286 ±98	(119-670)	34

Note: M = male participants F = female participants CV = coefficient of variation. All coefficient of variation values are reported as a percentage
*Significant difference between untrained participants and trained participants *$p < 0.05$, **$p<0.01$, ***$p<0.0001$

It follows that increased training adaptation would be expected to result in lower homeostatic stress during a standardized exercise bout. Therefore, it could be speculated that individual variation in HRR_{60s} may represent individual variation in both levels of training adaptation and homeostatic stress during an exercise bout, amongst individuals with a range of fitness levels.

The absence of a significant relationship between RPE and $EPOC_{MAG}$ in the current study is in keeping with previous reports of no significant difference in $EPOC_{MAG}$ between trained and untrained individuals exercising at a fixed $\%VO_2max$ [33, 34]. It would appear that a higher end-of-exercise VO_2 and faster recovery rate among trained individuals and a lower end-of-exercise VO_2 and slower recovery rate among untrained individuals interact to produce similar overall magnitudes of EPOC between these groups following exercise at the same $\%VO_2max$ [34]. This phenomenon may help to explain why RPE was significantly associated with $EPOC\tau$, but explained less than 5% of the variation in $EPOC_{MAG}$ in the current participant group.

Limitations

As mentioned previously, the submaximal exercise bout in the current study was intended to be similar to a training session from a 12 week training program for novice runners on which our laboratory was also conducting research. However, prescribing the exercise bout according to distance produced inter-individual variation in both exercise duration and exercise EE. In retrospect, it would have been preferable to standardize one of these exercise parameters to aid interpretation of the current findings.

CONCLUSIONS

In the current study, HRR_{60s}, $EPOC\tau$ and $HRR\tau$ were significantly associated with the RPE of the preceding exercise bout whereas there was no significant association between RPE and $EPOC_{MAG}$. Of these recovery measurements, HRR_{60s} had highest overall correlation with RPE ($r = -0.69$) and shows modest potential to represent inter-individual variation in the homeostatic stress of a standardized exercise bout in a group with a wide range of fitness levels. A practical application of this finding could be to retrospectively detect and/or account for inter-individual variation in homeostatic stress using HRR_{60s}, given that it is challenging to prospectively prescribe an equivalent exercise stress in different individuals [35].

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