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ORIGINAL ARTICLE

# Maximal rate of heart rate increase correlates with fatigue/recovery status in female cyclists

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**Abstract**

*Purpose* Being able to identify how an athlete is responding to training would be useful to optimise adaptation and performance. The maximal rate of heart rate increase (rHRI), a marker of heart rate acceleration has been shown to correlate with performance changes in response to changes in training load in male athletes; however, it has not been established if it also correlates with performance changes in female athletes.

*Methods* rHRI and cycling performance were assessed in six female cyclists following 7 days of light training (LT), 14 days of heavy training (HT) and a 10 day taper period. rHRI was the first derivative maximum of a sigmoidal curve fit to R-R data recorded during 5 min of cycling at 100 W. Cycling performance was assessed as work done (kJ) during time-trials of 5 (5TT) and 60 (60TT) min duration.

*Results* 5TT was possibly decreased at HT (ES ± 90% confidence interval $= -0.16 \pm 0.25$; $p = 0.60$), while, 5TT and 60TT very likely to almost certainly increased from HT to taper ($\text{ES} = 0.71 \pm 0.24$; $p = 0.007$ and $\text{ES} = 0.42 \pm 0.19$; $p = 0.02$, respectively). Large within-subject correlations were found between rHRI, and 5TT ($r = 0.65 \pm 0.37$; $p = 0.02$) and 60TT ($r = 0.70 \pm 0.31$; $p = 0.008$).

*Conclusions* rHRI during the transition from rest to light exercise correlates with training induced-changes in exercise performance in females, suggesting that rHRI may be a useful monitoring tool for female athletes.

**Keywords** Heart rate · Performance · Fatigue monitoring · Cycling · Autonomic function

**Abbreviations**

| | |
|---|---|
| FOR | Functional overreaching |
| NFOR | Non-functional overreaching |
| OTS | Overtraining syndrome |
| ANS | Autonomic nervous system |
| HR | Heart rate |
| HRR | Heart rate recovery |
| HRV | Heart rate variability |
| rHRI | Maximal rate of heart rate increase |
| LT | 7 day, light training period |
| HT | 14 day, heavy training period |
| 5TT | 5 min maximal cycling time-trial |
| 60TT | 60 min maximal cycling time-trial |
| kJ | Kilojoules |
| W | Watts |
| TRIMP | Training impulse |
| Bpm | Beats per minute |
| SD | Standard deviation |
| ES | Effect size |

## Introduction

Athletes rely on physical training to promote physiological adaptations which facilitate performance improvement. To

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maximise performance improvements, the balance between training stimulus and recovery needs to be optimised. For elite athletes, it is possible to induce a temporary imbalance between training stimulus and recovery [termed *functional overreaching* (FOR)] which may ultimately promote supercompensatory performance improvements (Meeusen et al. 2013). However, a prolonged imbalance between training stimulus and inadequate recovery can contribute to the development of performance-limiting conditions of non-functional overreaching (NFOR) or overtraining syndrome (OTS) (Kellmann 2010). Ideally, an athlete's fatigue/recovery status could be deduced by a simple-to-assess marker, since this would allow training to be modified to prevent the progression from FOR to NFOR, and the potential development of OTS (Meeusen et al. 2013).

Autonomic nervous system (ANS) function is altered through athletic training (Borresen and Lambert 2008) and because heart rate (HR) is regulated by the ANS, changes in HR parameters have been used to infer changes in ANS function in response to training (Buchheit 2014). Common HR parameters assessed include HR variability (HRV) and HR recovery (HRR) (Buchheit 2014), however, recent evidence suggests that measures of HR kinetics at exercise onset may also be useful markers of how an athlete is responding to changes in training (Bellenger et al. 2016a). Studies have shown the maximal rate of HR increase (rHRI) correlated with performance decrements induced by both acute (Thomson et al. 2015) and chronic training (Bellenger et al. 2015; Nelson et al. 2014), in addition to performance improvements resulting from physiological adaptation (Bellenger et al. 2017).

Although rHRI has promise as a marker of fatigue/recovery, studies to date have been conducted in male athletes only. Some studies have shown that females differ from males in their autonomic response to training, in that for a comparable amount of training, female athletes maintain a higher level of cardiac parasympathetic tone (as assessed by HRV) (Fürholz et al. 2013; Hedelin et al. 2000). The effect of this gender-based difference in parasympathetic tone on the ability for rHRI to correlate with training-induced changes in exercise performance is unknown. Thus, the aim of this study was to investigate if rHRI correlated with training-induced changes in exercise performance in female athletes following a period of heavy overload training and subsequent taper.

## Methods

### Participants and study design

Seven competitive female cyclists were recruited from cycling clubs in Adelaide, South Australia. Ethical approval was granted by the University of South Australia Human Research Ethics Committee in accordance with the Declaration of Helsinki, and all volunteers provided written informed consent prior to participation. Cycling performance and rHRI were tested at three separate time-points: at the completion of 7 days of light training (LT), representing baseline; at the completion of 14 days of heavy training (HT) which aimed to induce FOR; and following a 10 day taper period which facilitated physiological adaptation.

### Measurements

Cycling performance was assessed during 5 (5TT) and 60 (60TT) min time trials, performed on an electronically braked cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, Netherlands) with the performance measure being work done, expressed as kJ. rHRI was assessed during a 5-min cycling bout at 100 W. rHRI assessment was preceded by 4–6 min of quiet sitting on the cycle ergometer, with the participant only being informed of when to start cycling, to reduce the potential of an anticipatory rise in resting HR. HR data (R-R intervals) were recorded throughout all tests using an RS800CX HR monitor (Polar Electro Oy, Kempele, Finland).

rHRI was quantified by fitting a 5-parameter sigmoidal curve to R-R interval data recorded during the rHRI assessment. The R-R data consisted of 30 s prior to exercise onset, and the subsequent 5 min of steady state exercise. rHRI (bpm/sec) was the first derivative maximum of this curve, obtained using the solver function in Microsoft Excel (Microsoft Corporation, NY, USA), as described by Bellenger et al. (2017). Additionally, HR data were recorded at 15 s intervals during training for determination of training load using Training Impulse (Banister 1991) (TRIMP) (duration in minutes multiplied by % of peak HR).

### Training program

The training intervention utilised in this study has been previously described, and has been shown to induce overreaching in moderately well-trained athletes (Bellenger et al. 2017). Briefly, LT was designed to allow participants to be rested and recovered from any pre-study training prior to completing HT, and required 6 days of cycling for 30–60 min per day at 65–85% of peak HR. HT was intended to induce substantial fatigue and a state of FOR, requiring 124 min of cycling per day, with 34% of the training performed above 88% of peak HR. Taper was designed to facilitate supercompensatory performance improvement, and consisted of seven training sessions of 30–60 min per day at 65–85% of peak HR, and one interval session (four repeats of 3 min at 69–81% peak HR followed by 2 min at 88–92% peak HR) to provide some variety in training.

### Statistical analysis

Data were analysed using PASW Statistics 18.0 (SPSS, Chicago, IL, USA) and presented as mean ± standard deviation (SD), and as effect size (ES) with 90% confidence intervals. Data were log transformed to minimise bias from non-uniformity of error (Hopkins et al. 2009) and performance and rHRI measures were compared across time-points using repeated measures analysis of variance with Bonferroni post hoc comparison, with statistical significance for all tests set to $p < 0.05$. Data were also analysed through magnitude-based inferences by calculating ES between focus time-points using pooled SD. Thresholds for ES statistics were ≤ 0.2 (trivial), > 0.2 (small), > 0.6 (moderate), > 1.2 (large), > 2.0 (very large) and > 4.0 (extremely large) (Hopkins et al. 2009). Probabilities to establish differences between time-points as lower, similar or higher than the smallest meaningful effect [calculated using previously published coefficients of variation for rHRI, 5TT and 60TT (Nelson et al. 2014)] were interpreted as < 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99%, very likely and > 99%, almost certain (Hopkins et al. 2009). Within-subject correlations between rHRI and performance parameters were evaluated using univariate analysis of covariance (Bland and Altman 1995), with *r* values evaluated according to Hopkins et al. (2009).

## Results

Six participants completed the study (age 36.6 ± 4.0 years, body mass 65.0 ± 4.7 kg). One participant was unable to tolerate the demands of the heavy training and consequently withdrew from the study. Participants were completing a mean of 7.5 h training per week (range 6–11 h). The weekly training duration during LT represented a 40% decrease compared to the participant's typical weekly training duration, while HT represented a 100% increase in typical weekly training duration. Daily TRIMP in the six completed participants almost certainly increased from 2617 ± 445 units at LT to 9341 ± 1133 units at HT (ES = 7.66 ± 1.19; $p < 0.001$), and then almost certainly decreased to 2216 ± 286 units from HT to taper (ES = − 8.61 ± 0.87; $p < 0.001$). Work done during 5TT and 60TT was 62.6 ± 6.6 and 540.7 ± 92.0 kJ, respectively at LT. 5TT was possibly decreased from LT to HT (ES ± 90% confidence interval = − 0.16 ± 0.25; $p = 0.60$), while change in 60TT was unclear at this time-point (ES = − 0.12 ± 0.23; $p = 0.82$). From HT to taper, 5TT and 60TT very likely to almost certainly increased (ES = 0.71 ± 0.24; $p = 0.007$ and ES = 0.42 ± 0.19; $p = 0.02$, respectively). Two of the six completed participants increased their exercise performance at HT and were, therefore, not considered to be overreached. Excluding these participants from analysis [since their response would attenuate the true effect of overreaching on performance and rHRI (Bellenger et al. 2016a)] resulted in a likely to very likely decrease in 5TT (ES = − 0.27 ± 0.15; $p = 0.07$) and 60TT (ES = − 0.24 ± 0.21; $p = 0.19$) from LT to HT, and a very likely to almost certain increase following taper in comparison to HT (ES = 0.73 ± 0.05; $p = 0.002$ and ES = 0.39 ± 0.16; $p = 0.04$, respectively; Fig. 1a, b). rHRI was 6.48 ± 2.33 bpm/s at LT in the six completed

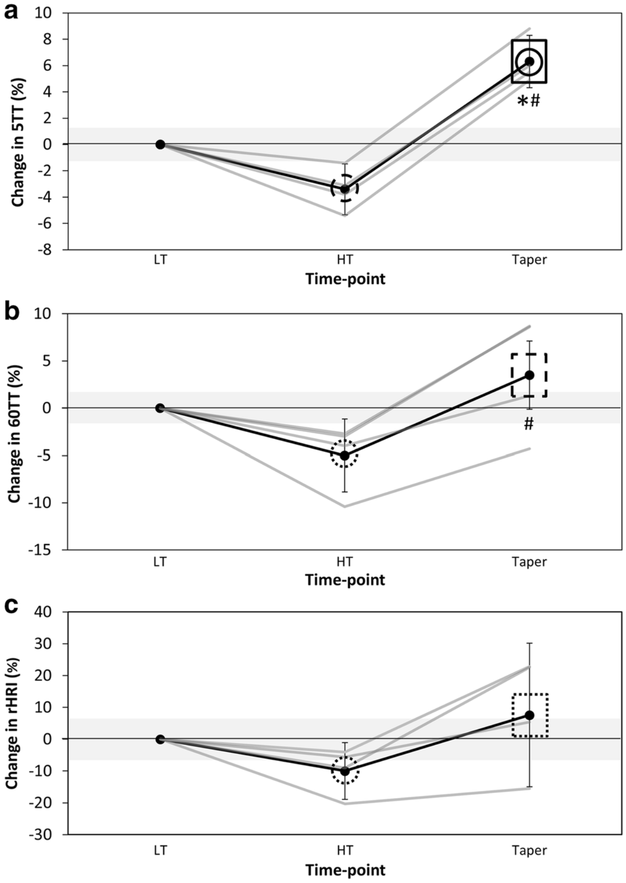

**Fig. 1** Percentage change in **a** cycling performance on a 5 min maximal time trial, **b** cycling performance on a 60 min maximal time trial, and **c** maximal rate of heart rate increase from LT. Data are mean ± 90% confidence interval. Grey shaded areas represent the smallest worthwhile change. *5TT* 5 min maximal cycling time trial, *60TT* 60 min maximal cycling time trial, *rHRI* maximal rate of heart rate increase, *W* watts, *LT* light training, *HT* heavy training. Grey lines, individual responses for each participant; black line, mean response of participants; dotted circle, likely chance of practically meaningful difference in value from LT; dashed circle, very likely chance of practically meaningful difference in value from LT; continuous circle, almost certain chance of practically meaningful difference in value from LT; dotted square, likely chance of practically meaningful difference in value from HT, dashed square, very likely chance of practically meaningful difference in value from HT; continuous square, almost certain chance of practically meaningful difference in value from HT; (asterisk) significantly different ($p < 0.05$) from LT; (hash) significantly different ($p < 0.05$) from HT

participants, and the change in this variable was unclear at HT (ES = − 0.02 ± 0.32; $p$ = 1.00) and possibly increased following taper in comparison to HT (ES = 0.24 ± 0.29; $p$ = 0.50). rHRI was 7.25 ± 2.57 bpm/s at LT in the four participants who experienced a decline in performance, and relative changes at HT and taper are shown in Fig. 1c.

Large within-subject correlations (using LT, H and taper time-points) were found between rHRI, and 5TT ($r$ value ± 90% confidence interval = 0.65 ± 0.37; $p$ = 0.02) and 60TT ($r$ = 0.70 ± 0.31; $p$ = 0.008), which were strengthened when excluding the two participants who improved their performance at HT ($r$ = 0.74 ± 0.38; $p$ = 0.02, Fig. 2a, $r$ = 0.80 ± 0.32; $p$ = 0.009, Fig. 2b, respectively).

## Discussion

This study aimed to evaluate the correlation between rHRI and fatigue/recovery status in female cyclists. The main finding was the positive correlation between rHRI assessed during the transition from rest to light exercise (100 W) and exercise performance in female athletes on

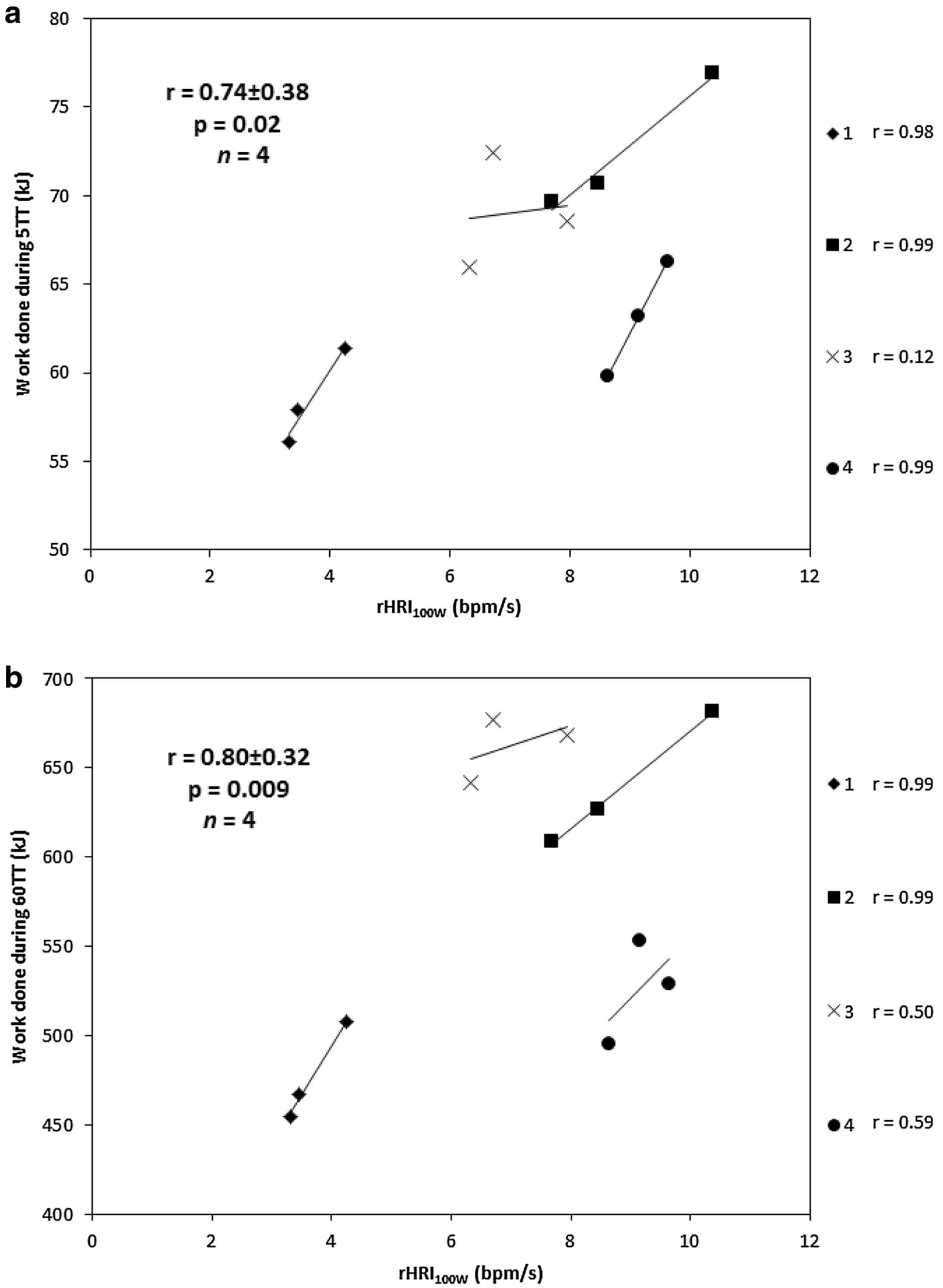

**Fig. 2** Within subject correlations between maximal rate of heart rate increase and cycling performance on (**a**) a 5-min time trial, and (**b**) a 60-min time trial. Key at right of figure indicates the relevant participant (1–4), and the individual $r$ value for each participant. *5TT* 5-min maximal cycling time trial, *60TT* 60-min maximal cycling time trial, *kJ* kilojules, *rHRI* maximal rate of heart rate increase, *bpm* beats per minute, *s* second, *n* number of participants

both 5TT and 60TT. This correlation indicated that as the participants increased their training load and experienced a decline in performance (i.e. a state of overreaching or negative training adaptation), rHRI slowed or decreased, however, when the participants subsequently reduced their training load and realised a supercompensatory increase in performance (i.e. a positive training adaptation), rHRI increased. This relationship is consistent with that of previous rHRI research in male athletes which has shown that rHRI correlates with both performance decrements resulting from heavy training (Nelson et al. 2014), and performance improvements facilitated by taper periods (Bellenger et al. 2017), although the correlations found in the current study are stronger than those seen in previous studies. This suggests that rHRI may be a useful marker of training-induced changes in exercise performance in both female and male cyclists.

Recent evidence has suggested that female athletes have an altered autonomic response to training compared to their male counterparts. Fürholz et al. (2013) found that female athletes have a higher proportion of parasympathetic modulation (indicated by greater high frequency HRV) for a comparable training load when compared with male athletes. Although these gender differences have not been found in all studies (Schäfer et al. 2015), similar findings have been shown by Hedelin et al. (2000), who found female adolescent cross-county skiers have consistently increased parasympathetic modulation (assessed through HRV) when compared with their male counterparts who completed a comparable amount of training. While this may indicate an altered autonomic response in female athletes, this does not appear to alter the ability of rHRI to correlate with training-induced changes in exercise performance in females.

Other HR parameters have also been used to indicate overreaching in female athletes. A recent study by Decroix et al. (2017) found that HR Recovery (HRR) after a standardised submaximal exercise test was likely faster following 5 days of training designed to induce overreaching, and was likely slower following 3 days of subsequent recovery. All athletes within this study were likely overreached based on a significant increase in self-reported fatigue status, RPE and the inability to reach 90% of maximal HR. This indicates that an increased HRR may reflect overreaching and decreased HRR may reflect subsequent recovery in female athletes following a period of heavy training. In addition, studies investigating HRV in female athletes (Uusitalo et al. 2000; Hedelin et al. 2000; Schäfer et al. 2015; Flatt et al. 2017), have suggested that following periods of intensified training there is a shift towards resting parasympathetic hyperactivity, although the results of relevant studies have been somewhat equivocal. However, increased parasympathetic activity might also explain the faster HRR observed by Decroix et al. (2017) as a more rapid reintroduction of parasympathetic activity after submaximal exercise would be expected to decrease HR more rapidly.

In addition to the HR parameters assessed in female athletes, the same HR parameters have been commonly assessed in male athletes as an indicator of training-induced performance changes. Multiple studies (Bosquet et al. 2003; Dupuy et al. 2013; Buchheit et al. 2010; Kiviniemi et al. 2007; Oliveira et al. 2013) have assessed HRV during periods of intensified training, and have found parasympathetic hyperactivity at rest coincides with increases in exercise performance. However, similar findings have also been made following periods of overreaching in male athletes (Le Meur et al. 2013; Bellenger et al. 2016b, 2017), suggesting that HRV may change in a similar manner following both periods of overreaching and physiological adaptation. Similarly, studies in male athletes (Buchheit et al. 2008, 2010; Lamberts et al. 2009; Capostagno et al. 2014) have found that HRR is increased following periods of intensified training that elicits improvements in performance. However, it also appears that HRR can increase with training that elicits overreaching (Thomson et al. 2016; Decroix et al. 2017; Bellenger et al. 2017; Aubry et al. 2015). This was confirmed in a recent meta-analysis (Bellenger et al. 2016a) which found that HRR experiences a paradoxical relationship with training status, in that it increases during periods of intensified training which causes a decrease in exercise performance, and also following subsequent taper periods which result in positive physiological adaptation and an increase in performance. This suggests that although HRV and HRR may be able to indicate that a change in training status has occurred, they should be interpreted in the context of the relevant training phase (Aubry et al. 2015). However, rHRI might be a more adapted marker of training-induced changes in exercise performance as it indicates both positive and negative shifts in exercise performance resulting from intensified training.

Assessment of rHRI at 100 W in the present study was intended to elicit a plateau HR of ~65% of maximal HR (~120 bpm), and given that an increase in HR from rest to 115–120 bpm is primarily due to the withdrawal of parasympathetic modulation (Robinson et al. 1966), it was hypothesised that rHRI at this workload would primarily reflect parasympathetic withdrawal. As female athletes typically exhibit a high proportion of parasympathetic modulation, this may partially explain the ability of rHRI to track training-induced changes in performance, as training-induced changes in parasympathetic modulation may be better reflected through workloads which illicit a HR response which is predominately modulated by parasympathetic withdrawal.

The rHRI values reported in this study were similar to those seen during 100 W cycling exercise in male athletes (Nelson et al. 2014), indicating a similar rate of HR acceleration in both genders at exercise onset. The enhanced parasympathetic modulation previously reported in female athletes (Hedelin et al. 2000; Fürholz et al. 2013) may have theoretically led to a higher rHRI value than those previously reported in male athletes, given that an increased level of resting parasympathetic cardiac modulation is generally thought to lead to an increase in HR acceleration, due to increased levels of parasympathetic withdrawal (Robinson et al. 1966), however, this does not appear to be the case. Interestingly, although there was no direct comparison of male and female athletes in the present study, the strength of the relationships between rHRI and exercise performance were stronger than have been seen in previous studies in males. This suggests that changes in rHRI might be mediated more strongly by changes in parasympathetic cardiac autonomic modulation.

Although this study was limited by both the small sample size ($n = 6$) and the small number of data points per athlete ($n = 3$), it did not affect the overall results, with large correlations being found regardless. Nevertheless, future research should confirm the results of this study in a larger cohort of athletes of different training levels, including elite athletes in whom the monitoring of fatigue/recovery status is especially important. Additionally, this study successfully used absolute workloads to assess rHRI, however, it should be noted that absolute workloads may alter the contributions of parasympathetic and sympathetic modulations in athletes with differing levels of fitness. Further, this study quantified rHRI during the transition from rest to light activity. A recent study by Bellenger et al. (2017) attempted to determine if rHRI assessed during different exercise intensities is better correlated with exercise performance following periods of intensified training, and found that rHRI assessed during the transition from rest to 120 W of cycling was best correlated with exercise performance. However, the current study did not assess whether rHRI assessed during different exercise intensities correlated differently, so it is unknown if the transition from rest to light exercise is an optimal method for assessing rHRI in female athletes. From a practical perspective, the findings of this study indicate that rHRI may be a useful indicator of changes in exercise performance in female athletes. This finding suggests that rHRI may more useful for coaches/sports scientists compared to other HR derived markers of training status as it correlates with both fatigue-induced decreases and adaptation-induced increases in physical performance. However, at this stage no cut-off values have been identified for rHRI to indicate what magnitude of slowing in rHRI would indicate the need for an alteration in training. Future studies should aim to induce FOR in larger samples to allow for such cut-off values to be identified. Additionally, future studies should attempt to track rHRI over longer periods to determine if it has the ability to correlate with training induced changes in exercise performance over a full competitive season, rather than a single training phase.

## Conclusion

Training-induced changes in cycling exercise performance were correlated with changes in rHRI assessed during cycling at 100 W in female athletes. rHRI during the transition from rest to light exercise might be a useful indicator of how female athletes are responding to changes in training load to inform changes in training to optimise performance.

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### Compliance with ethical standards

**Conflict of interest** The University of South Australia has applied for a patent on the rHRI technology described in this manuscript, and researchers Davison and Buckley are employees of the University. Researcher Schäfer Olstad is an employee of Polar Electro Oy.

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