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Association of Heart Rate Variability and Simulated Cycling Time Trial Performance

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Abstract: The aim of this study was to determine if an abnormal HRV status would have negative effects on simulated individual time trial (ITT) performance in recreational cyclists. Recreational male (n=23, 42.8±8.3 years, 78.0±11.0 kg) and female (n=2, 37.0±6.8 years, 68.0±4.4 kg) cyclists completed simulated indoor 40-minute ITTs (40TT) over ten weeks. Participants were asked to complete simulated 40TTs under two HRV conditions: HRV normal values and HRV abnormal values. Participants recorded daily morning HRV readings to determine HRV status. Each participant performed all 40TTs on their personal indoor bike trainer and bike without external race simulation (e.g., Zwift). All cycling performance data were recorded on personal bike computers and submitted via a Qualtrics survey. A total of 138 ITTs (Normal = 75; Abnormal = 63) were assessed for relationships between HRV status and performance outcomes using a linear mixed-effects model with Cohen's D for effect sizes (ES). A significant main effect of HRV status was found for peak power (F = 6.61; Normal: 372 ± 121.5 watts; Abnormal: 349 ± 105.9 watts; 380; p = 0.01; ES = 0.20) and peak speed (F = 6.12; Normal = 10.8 ± 1.2 m/s; Abnormal: 10.4 ± 1.2 m/s; p = 0.02; ES = 0.33). No significant main effect or effect sizes exceeding 0.20 were observed for all other performance variables. Daily HRV monitoring provides valuable insight that an individual's peak power and speed may be compromised during cycling performance despite no changes in physiological or psychological indicators of effort. Coaches and cyclists can use morning HRV to inform race strategy ensuring desired performance outcomes, especially for those who rely on high power outputs.

Keywords: Heart rate variability; Time trial; Cycling

1. Introduction

The competitive road cycling season includes 90 to 100 competition days, which involve single day "Classic" races and "Tours" lasting one or more weeks (Lucia et al., 2001). Tour races have three primary competition requirements: flat stages, uphill cycling and individual time trials (ITT) (Lucia et al., 2001). ITTs fall under two categories: "short", lasting 5 to 10 km, and "long", lasting 10 to 60 km, during which average power reaches 350W and workloads around 90% of maximal aerobic capacity (Atkinson et al., 2003; Lucia et al., 1999; Padilla et al., 2000). The high physiological demands placed on cyclists' during ITT make it one of the most physically demanding events in competitive endurance sports (Lucia et al., 2001, 2003).

Maintaining peak physical capacity across the competitive cycling season is essential, and regular monitoring of individual responses to the competitive demands would provide valuable insight into the athlete's ability to perform. Heart rate variability (HRV) is a popular non-invasive tool for daily monitoring within endurance athletes (Makivic et al., 2013; Plews, Laursen, Kilding, et al., 2013). HRV is a surrogate index of the autonomic nervous system via the modulation of parasympathetic activity (Camm et al., 1996). Cardiac autonomic regulation is assessed via HRV by measuring time intervals between successive R-R intervals of heart beats, where an increase or decrease R-R interval duration reflects altered autonomic activity (Makivic et al., 2013). To appropriate changes in HRV, it is recommended that daily readings are averaged over a rolling seven-day period with calculated individual smallest worthwhile change windows (SWC), ±0.5 standard deviation) (Kiviniemi et al., 2010; Plews, Laursen, Kilding, et al., 2013; Vesterinen et al., 2016). Daily HRVs outside of the SWC window are a reliable measure to determine meaningful changes in physiological status or psychological states induced by training or daily stressors (Crawford et al., 2020; Plews et al., 2012). Thus, HRV reflects the individual responses to stress that can provide insight as to when an athlete may require rest or attenuated training loads to optimize athletic performance.

Currently, regular monitoring of HRV has shown promise for the prescription of training intensity/load for cycling and running (Javaloyes et al., 2019; Kiviniemi et al., 2010; Vesterinen et al., 2016). However, the effects of HRV on same day competitive cycling performance is unclear. Le Meur et al (2013) observed a positive relationship with swim performance and the high frequency (HF) domain of HRV, representing parasympathetic activity, while a negative relationship occurred with swim performance and the low frequency (LF) domain of HRV, which is influenced by both parasympathetic and sympathetic activity. Alternatively, Coates et al (2018) found that same day HRV measures were insufficient in predicting alterations to incremental cycling performance. Therefore, the purpose of this investigation was to determine the effects of individual HRV status on performance metrics of ITTs. We hypothesize that a HRV status which falls outside an individual's SWC window on the day of an ITT will result in impaired cycling performance metrics (i.e., total distance, peak and average speed, and peak and average power) compared to days in which HRV status is deemed "normal".

2. Materials and Methods

Subjects — Twenty-five trained to well-trained cyclists as determined by frequency and duration of training (23 men, 2 women) were recruited for this study (Jeukendrup et al., 2000). All participants performed at least three 60-minute rides per week for at least one year prior to enrollment. Participant inclusion criteria included: ownership of heart rate monitor, a road bicycle, indoor bike trainer (wheel-on or direct drive train), and a bike computer or smartphone application capable of recording the study performance metrics. Exclusion criteria included: a physical condition or medication which may contraindicate vigorous physical or artificially regulate heart rhythms (i.e., beta blockers). Participant characteristics are presented in Table 1. This study was performed in accordance with the Declaration of Helsinki and was approved by the Kansas State University Institutional Review Board (#10217). All participants provided informed consent prior to study commencement.

Table 1: Participant Characteristics

	Age (years)	Mass (kg)
Male (n = 23)	42.8 ± 8.3	78.0 ± 11.0
Female (n = 2)	37.0 ± 6.8	68.0 ± 4.4
Combined	42.4 ± 8.17	77.5 ± 10.6

Design— This study used a 12 week quasi-experimental repeated-measures design to test the effects of HRV status on simulated 40-minute ITT (40TT) performance metrics (e.g., distance; speed, and power). Participants were recruited from around the world via social media marketing (e.g., Facebook, Instagram). Once participants were screened and enrolled, they completed 14 days of resting HRV measurements, in order to establish individual SWC windows. After individual SWC windows were established, participants continued recording morning HRV readings and began performing the simulated 40TTs. Participants were asked to perform a total of six 40TTs: three trials after a normal HRV status measure and three trials after an abnormal HRV status measure as determined by the HRV4Training application. At least 48 hours separated each 40TTs. Upon completion of each 40TT, participants submitted performance metrics to the research team. Throughout the study participants were asked to not alter training or start a new training regimen.

Heart rate variability (HRV) – Morning HRV was measured daily throughout the study. All participants were instructed to measure their pulse-rate intervals upon waking and after emptying their urinary bladder. HRV was measured in a supine position for 1-minute; participants were instructed to lie still and not perform any further activity once the recording was started (Plews et al., 2017). The HRV measurements were captured with the commercially available smartphone application HRV4Training (https://www.hrv4training.com/). The HRV4Training software uses photoplethysmography to determine the variability in successive R-R intervals during continuous heart rate data (Plews et al., 2017). The HRV4Training application has a built-in methodology for signal filtering, processing, interpolation, artifact correction, and R-R peak detection which can be found in the reference for the application development (Plews et al., 2017). For day-to-day monitoring of individual recovery (i.e., sympathovagal balance) HRV was measured as the root mean squared of successive differences (RMSSD) and due to its lack of normality was transformed using the natural logarithm (LnRMSSD). Then, LnRMSSD was multiplied by two so that LnRMSSD could be viewed on a scale of approximately one to ten for ease of participant interpretation (Williams et al., 2017). A rolling average of an individual's HRV was calculated and used throughout the study to determine changes in vagal activity as it is more reliable measure than single day values. (Plews, Laursen, Stanley, et al., 2013). The HRV4Training application calculates individual SWC windows based on seven-day rolling average HRV. A day of HRV reading outside of the individual SWC was deemed as an abnormal HRV, while an HRV within the individual SWC was deemed as a normal HRV.

40-minute simulated individual time trial (40TT) – Cyclists performed six 40-minute all-out ITTs indoors on their own bike and cycling trainer without the use of virtual cycling programs (i.e., Zwift, Rouvy). Participants were asked to record environmental conditions (i.e., temperature, humidity), and were asked to keep them consistent on each 40TT. During all 40TTs, participants were instructed to wear a heart monitoring device (e.g., Polar, Garmin). Participants performed a 10-minute warm-up at a constant work rate of 50 watts prior to each 40TT. Participants immediately initiated the 40TT after the warm-up and were allowed to change their gear ratio and pedal frequency and drink water ad libitum. Each 40TT was followed by a 10-minute cool-down. Average and peak power, average and peak heart rate (HR), average and peak speed and total distance were recorded for each 40TT via cycling computer or application (e.g., Polar, Garmin, Strava and Wahoo). Descriptive information for the equipment used by the participants is provided in Table A1.

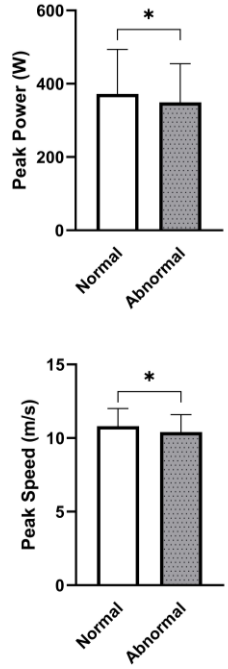
Table A1. Descriptives of equipment used by participants

Indoor Bike Trainer Brand	Bike Computer Brand	Heart Rate Monitor Brand	Speed or Watt Sensor Brand
Wahoo (11), Elite (5), Tacx (2), Saris (1), Jetblack (1), Computrainer (1), CycleOps (1), Real axiom (1), Kinetic (1)	Garmin (19), Wahoo (5), Samsung (1)	Garmin (15), Wahoo (6), Decathlon (2), Polar (1), Sigma (1)	Garmin Vector (6), Wahoo (5), Assioma (4), 4iiii (3), Stages (2), Magene (1)

Additionally, participants recorded their rate of perceived exertion (RPE) upon completion of the 40TT. All data was submitted to the research team via a Qualtrics (Provo, UT) survey.

Statistical Analysis— Data were analyzed using the R statistical computing environment and language (R Core Team, 2020) via the Jamovi graphical user interface (The Jamovi Project, 2020). Descriptive statistics were calculated, and all dependent variable data were checked for normality prior to inference testing. Relationships between the fixed effect (i.e., HRV status) and performance outcomes (i.e., average and peak HR, average and peak power, average and peak speed, RPE, and distance) data were assessed using linear mixed-effects models via the *GAMLj: General analysis for linear models* Jamovi module (Gallucci, 2019). Individual participants identifiers were input as the random factors within these models and a correlation matrix was used to determine covariates. When appropriate, covariates used for each respective performance outcome are noted below. Age was included as a covariate for peak speed, peak power, and RPE. Weight was included as a covariate for average power. Age and weight were included as covariates for max HR and average HR. An alpha level of 0.05 was used for all statistical inferences and post hoc comparisons were adjusted using the Bonferroni correction. Cohen's D was used to estimate observed effect sizes (ES) between HRV statuses. ESs were classified as small (0.2), medium (0.5), and large (0.8) (Cohen, 1988). Individual SWC windows were calculated for performance metrics during normal HRV 40TTs. Performance metrics during abnormal HRV 40TTs were compared against individual SWC windows to determine whether individual performance was altered beyond day-to-day variability. All data are reported as mean ± standard deviation.

Figure 1. Comparison of performance outcomes; peak watts and peak speed.



3. Results

A total of 138 ITTs were analyzed (Normal: 75; Abnormal: 63). Of the 138 HRV readings associated with the ITTs 3 had poor readings, 14 had readings and 121 had optimal readings. Differences in peak power and peak speed are shown in Figure 1.

A significant main effect of HRV status was observed for peak power (F = 6.61; Normal: 372 ± 121.5 watts; 95% CI = 341, 403; Abnormal: 349 ± 105.9 watts; 95% CI = 318, 380; p = 0.01; ES = 0.20) and peak speed (F = 6.12; Normal = 10.8 ± 1.2 m/s; 95% CI = 10.1, 11.5; Abnormal: 10.4 ± 1.2 m/s; 95% CI = 9.7, 11.1; p = 0.02; ES = 0.33). No significant main effects were observed for total distance (F = 1.95; Normal = 22.2 ± 2.79 km; 95% CI = 20.3, 24.0; Abnormal: 21.7 ± 2.95 km; 95% CI = 20.0, 23.7; p = 0.17; ES = 0.17), average speed (F = 0.74; Normal = 6.2 ± 0.49 m/s; 95% CI = 5.6, 6.7; Abnormal: 6.0 ± 0.49 m/s; 95% CI = 5.6, 6.6; p = .39; ES = 0.05), average power (F = 0.59; Normal = 236 ± 45.58 W; 95% CI = 220, 252; Abnormal: 234 ± 36.83 W; 95% CI = 218, 250; p = 0.45, ES = 0.05), peak HR (F = 0.07; Normal = 171 ± 17.59 bpm; 95% CI = 167, 176; Abnormal: 171 ± 15.13 bpm; 95% CI = 167, 176; p = 0.79, ES = 0.00), average HR (F = 0.05; Normal = 155 ± 17.13 bpm; 95% CI = 150, 161; Abnormal: 156 ± 17.13 bpm; 95% CI = 151, 161; p = 0.83, ES = 0.06) and RPE (F = 0.05; Normal = 8.97 ± 1.24; 95% CI = 7.59, 8.56; Abnormal: 8.05 ± 1.24; 95% CI = 7.56, 8.54; p = 0.83, ES = 0.02). Table 2. displays the number of individuals with an altered 40TT performance when HRV was abnormal. 40TTs with an abnormal HRV resulted in altered peak watts for 70% of participants, peak speed for 55% of participants, and average speed for 58% of participants.

Table 2. Individuals with a performance outside of their SWC window when HRV was altered.

Performance Metric	Individuals affected
Total Distance (km)	8/22 (36%)
Peak speed (m/s)	12/22 (55%)
Average speed (m/s)	7/22 (32%)
Peak watts (W)	14/20 (70%)
Average watts (W)	11/19 (58%)

Figure A1 displays a representation of the longitudinal monitoring of heart rate variability throughout the study and 40TT test days for a single study participant. An example of within subject performance differences is displayed in Table A2.

4. Discussion

The purpose of this investigation was to determine the effects of HRV status on physiologic and performance metrics of simulated 40TTs in trained to well-trained cyclists. As a result of our findings, we reject our hypothesis that HRV would be related today of performance. Importantly, we show that day of HRV readings do not significantly influence performance metrics of an ITTs in trained cyclists. Additionally, we demonstrated that no effects were observed on physiological (i.e., HR) or psychological (i.e., RPE) indicators of effort during ITTs. However, we did observe that when an abnormal HRV status occurred an individual's ability to produce peak power and peak speed was reduced potentially decreasing/impairing distance covered during a simulated ITT.

To the best of our knowledge, this is the first study to investigate the effects of same day HRV status on simulated cycling performance without a training intervention.

Figure A1. Representation of the longitudinal monitoring of heart rate variability throughout the study and 40TT test days for a single study participant.

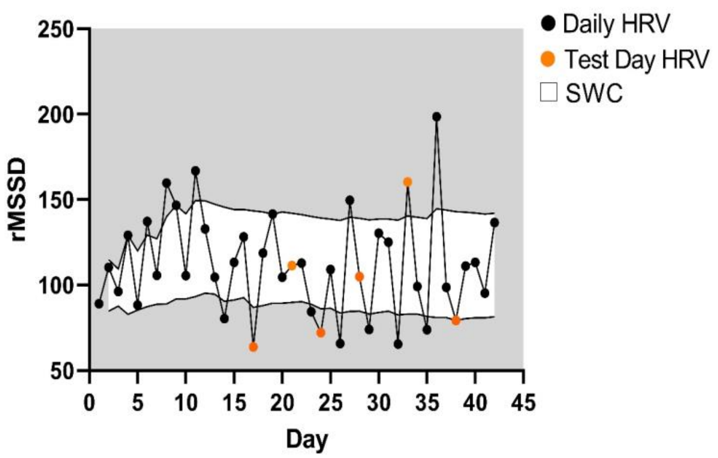


Table A2. Within subject performance differences

Performance Metric	Within normal HRV	Outside Normal HRV
Total Distance (km)	20.39 ±0.18	20.22 ±0.29
Peak heart rate (bpm)	175.00 ±2.00	175.67 ±1.11
Average heart rate (bpm)	166.00 ±0.00	167.00 ±0.67
Rating of perceived exertion	10	10
Peak speed (m/s)	8.88 ±0.05	8.87 ±0.07
Average speed (m/s)	8.49 ±0.06	8.43 ±0.14
Peak watts (W)	258.00 ±16.00	250.33 ±5.78
Average watts (W)	187.00 ±3.33	182.67 ±6.44

Our findings corroborate those of Coates et al. (2018) in which same day resting HRV were insufficient in predicting alterations in objective measures of performance during incremental cycling tests. Additionally, the lack differences in RPE between normal and abnormal HRV status during the 40TT, similar to reports of female cyclists competing on the Tour de France circuit (Barrero et al., 2019). Collectively, these findings further support the notion that temporary shifts in ANS activity do not play a significant role in performance capacity and should not be used as a predictor of performance. Instead, HRV should be tracked longitudinally to assess the ability of individual to adapt to training stress (Altini et al., 2020; Boullosa et al., 2021; Flatt & Esco, 2016).

Interestingly, we did observe significant differences in peak power and peak speed when a day of HRV status was abnormal. Previously, it has been shown that increases in high frequency spectral component of HRV, reflecting parasympathetic activity, has been associated with superior performance outcomes in swimmers (Atlaoui et al., 2007; Chalencon et al., 2012). Additionally, increases LnRMSSD is related to maximal aerobic running speed during both 10 km (Buchheit et al., 2010), and 21 km performances (Boullosa et al., 2021). However, with our participants the changes in peak power and peak speed were observed during increases and decreases in HRV. We would speculate that our observed differences are due to individual changes in 40TT strategy and not HRV status.

A key strength of this study is the high external validity. This was one of the first studies to directly compare HRV and same day performance for participants training and performing in free-living conditions. Thus, our study is the first to reflect the current state of remote/distance coaching of athletes. Additionally, participants completed multiple simulated 40TTs within each HRV condition. This study presents three main limitations. First, we were unable to control each participant's training load and prescription. Second, as we were not able to predict when an HRV would fall outside a SWC, we could not standardize the time between 40TTs, nor the time of day that each 40TT was performed. Finally, with all 40TTs being performed remotely, we were unable to perform additional measurements that would provide insights into any mechanistic changes occurring during the 40TTs.

This study demonstrated two important findings. First, an abnormal HRV status did not significantly alter performance during simulated 40TT performances. Second, intra-performance markers of physiological and psychological intensity were not influenced by acute changes in HRV. Future research with increased internal validity control and additional pre-performance metrics are required to better predict changes in simulated ITT performance. Additionally, future research should aim to include a larger portion of females to reflect the recreational cycling community as a whole.

5. Practical Applications.

Coaches and sports scientists who aim to optimize cycling performance need to gain insight into the athlete's physical capacity on race day. Daily monitoring of HRV seems to provide valuable information regarding whether an individual's peak power and speed may be compromised the day of a critical ITT performance. However, average cycling performance does not appear to be compromised with an acutely altered HRV status. Coaches and cyclists may choose to use morning HRV to inform race strategy (i.e., domestique selection). Additionally, power-based cycling events (e.g., criterium and track cyclists) may experience greater performance changes due to altered HRV compared to their endurance-based counterparts.

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