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The physiological and psychological demands of amateur cyclists riding the full route of the Tour de France

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Abstract

The Tour de France represents one of the pinnacles of endurance performance, involving 21 days of cycling, covering more than 3,500km and 50,000m of vertical ascent. Usually, the Tour de France is the sole domain of professional athletes, however, it has become more common for amateurs to complete the identical route in the same number of days as their professional counterparts. The aim of this investigation was to determine the physiological and psychological impact of completing the Tour de France in a cohort of amateur riders. A total of 16 riders completed the 2021 Tour de France route and participated in this study. Data were collected to characterise training in the preceding months (March - June 2021). Power and heart rate were collected throughout the event, alongside daily questionnaires regarding mood, perceived effort and sleep quality. Riders experienced ~300% increase in training load. Physiological markers indicative of overtraining and central nervous system dysfunction within the first four days of the Tour de France were present. There was a decline in both mean and maximal power and heart rate, which was evident throughout the 21 stages and is consistent with symptoms of non-functional overreaching. Compared to professionals, the present cohort experienced a higher TSS, TSS·km^{-1} and total work done per stage, indicating a higher relative intensity in amateur riders completing a 21-day cycling Grand Tour.

Keywords

Endurance training; Non-functional overreaching; Overtraining syndrome; Fatigue; Central nervous system; Grand Tour

1 Introduction

Effective endurance training for events such as the Tour de France, requires significant training load, and a balance between training stress and recovery. The intention is to generate periods of fatigue and subsequent recovery, which are proposed to result in a "*supercompensation*" effect on performance (Meeusen et al., 2013a). This concept has been termed functional overreaching. Conversely, where training is progressed without including periods of reduced training load, athletes can move into a state of "non-functional overreaching" (NFOR). Non-functional overreaching may result in a short term (weeks to months) decline in performance (Halson et al., 2002a; Meeusen et al., 2013b) and is associated with changes in numerous physiological markers including hormonal (Hough, Corney, Kouris, & Gleeson, 2013), suppressed cardiac function, increased oxygen uptake, increased rating of perceived exertion, and deterioration of mood states (Halson et al., 2002b). During periods of intensified training, symptoms common with NFOR can be induced in as little as 7-days of intensified training and can take several weeks or months to reverse (Halson et al., 2002b). Therefore, appropriate rider monitoring to determine training load is critical to the success of any training programme or multi-stage endurance event.

In recent years, tools to measure and quantify training have become increasingly accessible to both recreational and elite athletes. The Training Stress Score (TSS™) represents one of the most widely used metrics for training load monitoring by athletes and coaches alike. The TSS™ is derived from power output data and provides an indicative score of the total stress induced by an individual training session. However, it is important to recognise that although widely used by coaches and athletes, working in sports such as cycling, running and triathlon, the validity of the various methods of measuring training load has been questioned (Passfield, Murias, Sacchetti, & Nicolò, 2022).

The popularity of amateur endurance cycling events which mirror the route completed by professional riders in the Grand Tours, Classics and Monuments, has increased. These events are non-competitive and do not have any specific performance-based entry requirements. Consequently, it is highly likely that many riders completing such an event are at a high risk of symptoms associated with NFOR without appropriate insight into the event demands for amateur riders. Several studies have quantified the energetic and physical demands of both training and racing in professional cyclists (Jeukendrup, Craig, & Hawley, 2000; Sanders & Heijboer, 2019a; Saris, van Erp-Baart*, Brouns, Westerterp, & Hoor, 1989; Van Erp, Hoozemans, Foster, & De Koning, 2020; van Erp & Sanders, 2020). A key area of focus of these papers is the distribution of training load among different physiological domains, based on either heart rate (HR) and/or power to determine an intensity distribution. Currently there are no equivalent papers in amateur riders, or data concerning the physiological and performance impact of riding a 21 stage Grand Tour.

The aim of this study was to determine the training characteristics and demands of completing a 21-day multistage, non-competitive, Grand Tour in a group of amateur riders, who had completed sub-optimal, time constrained training in preparation for the event, and the impact this has on the acute response to completing a 21 stage event. A secondary aim was to compare the physical demands of riding a Grand Tour for amateur and professional riders. It was hypothesised that amateur riders would experience significant physiological strain throughout the 21 stages and that this would manifest itself in symptoms consistent with NFOR. Secondly, it was hypothesised that given the anticipated longer riding time coupled with the higher physiological strain, this would result in a higher overall load in amateur riders.

2 Material and Methods

2.1 Participants

Table 1. Participant (n=16) characteristics on 18th June 2021 and training data for the period 1st January 2021 to 18th June 2021.

Participant Characteristics	
Age (years)	44 ± 16
Height (m)	1.76 ± 5.0
Weight (kg)	86 ± 11
Critical Power (CP; W)	272 ± 87
Training Data	
Total volume (hh:mm)	203:39 ± 20:10
Total distance (km)	5665 ± 1251
Total number of rides	123 ± 27
Mean distance per ride (km)	47 ± 11***
Average power (W)	185 ± 26*
Mean work done per ride (kJ)	965 ± 280***
Mean elevation per ride (m)	346 ± 195***
Tour de France data	
Total volume (hh:mm)	175:45 ± 00:49
Total distance (km)	3497
Total elevation climbed (m)	47429
Average power (W)	140 ± 20
Peak power (W)	1010 ± 291
Mean work done per ride (kJ)	3441 ± 1342
Mean elevation per ride (m)	2259 ±1305
Percentage time in	
Zone 1 power (%) (~70% LT1)	45 ± 14
Zone 2 power (%)	24 ± 12
Zone 3 power (%)	17 ± 5
Zone 4 power (%) (LT2/CP/FTP)	7 ± 4
Zone 5 power (%) (MAP)	3 ± 2
Zone >5 power (%)	4 ± 1

Data are presented as mean ± SD. LT1 = first lactate threshold; LT2 = second lactate threshold; CP = Critical Power; FTP = Functional Threshold Power; MAP = Maximum Aerobic Power. Significantly different to Tour de France data: ***P<0.0001, *P<0.05.

Sixteen trained cyclists (15 male, 1 female, performance level 3 (Pauw, Roelands, Geus, & Meeusen, 2013), agreed to participate in this study as part of their undertaking to ride the complete route of the 2021 Tour de France (June 19th – July 11th 2021). All participants gave written informed consent to participate in the study following ethical approval of the Human Invasive Research Committee at Nottingham Trent University (Application ID number 644). All participants followed a guided training programme provided to support the event. Twelve of the cohort include in this analysis employed a professional coach to prescribe a more individualised training plan. All plans were focused on improving endurance and employed a mix of methods aimed at doing so, including the use of interval training and traditional long endurance rides prescribed to heart rate of power. Participant characteristics and available training data are presented in Table 1.

2.2 Route Details

The route was undertaken in 21 stages over 23 days, including two rest days (following stage 9 and stage 15). The route covered 3,497.1 km with an average stage length of 166.5 km (range 37.8 km to 254.1 km). Total time (including stops) was 175.8 ± 8.7 hours and average stage duration was 8.4 ± 2.7 hours. Out of the total time, 143.0 ± 7.3 hours was spent actively pedalling. The average speed over the 21 stages was 24.5 ± 3.8 kmph. Total vertical ascent was 47,429 m, with an average of 2,258 ± 1,305 m of ascent per stage (range 238 to 4,480 m). Stages were categorised according to the Tour de France organisers as flat, intermediate, or mountainous. In addition, there were two individual time trial stages, which for the purpose of analysis in this investigation were included within the flat stages.

2.3 Physiological Performance Data

2.3.1 Power

All on bike data were collected using the participants' own power meters (N=14). Participants were reminded to calibrate their power meters following the manufacturers' instructions prior to the start of each training ride or stage. All files were visually inspected for missing or erroneous data (e.g. power spikes, flat batteries, no connectivity) and removed from analysis. Power zones were determined based on critical power (CP), with CP being determined by Mean Maximal Power (MMP) data from the preceding 3 months, during which time riders were instructed to complete repeated maximal efforts of 180s and 720s to allow determination of CP and derivation of training intensity domains and zones (MacInnis & Gibala, 2017). Training zones 1 and 2 were defined as being below the first lactate threshold and in the moderate intensity domain. Zone 3 was between the first lactate threshold and 90% CP, equivalent to the heavy domain. Zone 4 was from 90% - 105% of CP, with zone 5 equivalent to 106-20% CP. The severe exercise domain was between CP and $\dot{V}O_{2max}$ (120% CP). Zone 6 was defined as anaerobic (121-150% CP) and zone 7 neuromuscular (>150% CP). Average power included time spent at 0W so long as the bike was moving >2 kmph. Total energy expenditure (EE, kJ) for the stage was calculated by the equation: Energy expenditure (kJ) = average power (W) * duration (s), where duration was the riding time for the stage.

2.3.2 Heart Rate

Participants used their own chest worn heart rate monitors (n=16) to collect all HR derived data. Maximal HR was determined by the highest achieved HR within the preceding 3 months of training data. A 5-zone model was determined based on HR at CP (MacInnis & Gibala, 2017).

All individual power and HR data were collected using Training Peaks (Training Peaks LLC, Louisville, USA) and Golden Cheetah (www.goldencheetah.org), capturing details of ride time, distance and elevation as well as time spent in each power and HR zone during each stage. In addition mean and maximum values for each participant were collected following each stage, with the change in absolute peak power and HR, and time in zone, being used as indicative of an alteration in autonomic function (Halson et al., 2002b). Power and HR data were used to calculate Intensity Factor (IF), Normalised Power® (NP™) and Training Stress Score® (TSS). These metrics have been proposed to be effective, and commonly used metrics to monitor acute stress experienced during cycling (Coggan, 2003). NP™ was calculated by determining the 30-s rolling power average, raised to the 4th with the average then calculated, with the 4th root of that value being taken as the normalised power for each stage. TSS was calculated using the following formula (Coggan, 2003):

TSS = [(t × NP™ × IF™)/(FTP × 3600)] × 100

where t is the duration of the exercise bout in seconds, NP™ is normalised power of the exercise bout (Coggan, 2003), and IF™ is intensity factor, which is the ratio between the NP and the rider's CP/Functional Threshold Power (Coggan, 2003). All riders were instructed to zero-calibrate power meters before every ride.

2.3.3 Self-report and Perceptual Data

Prior to the start of the event, each participant was provided with a data collection booklet which detailed each stage and contained all self-report questionnaires. Participants were given written and verbal instructions on how to complete the questionnaires and scales in the 2 weeks prior to the event. Each morning, participants were required to report their sleep duration, resting HR and urine colour (Armstrong et al., 1994). Stage RPE (Borg, 1982) was recorded immediately following each stage. In addition, 10 cm visual analogue scales with verbal anchors (0 mm: No symptoms; 100 mm: Most severe symptoms) were used to quantify the within stage severity of nausea, flatulence, abdominal discomfort, bloating, bowel urgency, diarrhoea, vomiting and belching.

The Profile of Mood States (POMS; (McNair, Maurice, & Droppleman, 1971)) was used to assess mood states. The POMS is an adjective checklist consisting of 65 items rated on a 5-point Likert scale ranging from 0 "not at all" to 4 "extremely". The adjectives related to the usual subscales of Tension-Anxiety, Depression-Dejection, Anger-Hostility, Fatigue-Inertia, Vigor-Activity, and Confusion-Bewilderment. As short-term effects on mood were of interest, we employed the "right now" response set used by Prapavessis and Grove (Prapavessis & Grove, 1994). Participants completed the POMS prior to the event, on rest day 1 (between stages 9 and 10), rest day 2 (between stages 15 and 16) and following completion of the event. POMS subscales (vigour, anger, fatigue, depression, tension) were calculated, and total mood disturbance (TMD) was calculated by the sum of anger, fatigue, depression and tension and subtracting the vigour score.

2.4 Professional vs Amateur Comparison

Data detailing the performance characteristics of multi day and Grand Tour professional stage races from Sanders et al (Sanders & Heijboer, 2019b) and Van Erp et al (van Erp & Sanders, 2020) (combined N=64) were compared to the present group. Differences between the professional cohort (van Erp & Sanders, 2020) and the amateur riders were determined for the impact of training status (amateur vs professional) and stage type (flat, intermediate and mountain) on RPE, TSS, TSS·km^{-1} and total work done (kJ and kJ·km^{-1}).

2.5 Statistical Analysis

Statistical analysis was conducted using Excel and GraphPad Prism (v9.4.1; GraphPad Software, LLC). All variables were tested for normality of distribution using the Shapiro-Wilk Test. Normally distributed data were analysed using a two-way repeated measures analysis of variance (ANOVA). Where data were characterised based on stage type, data were analysed using a one-way ANOVA. Non-normally distributed data pertaining to perceptual responses to individual stages were analysed using a Friedman test corrected for multiple comparisons using Dunn's test. Data comparing previously published data from professional stage races to the present amateur cohort's data used an unpaired Student's t-test. Correlational data were analysed using Pearson's correlation coefficient or Spearman's r where appropriate. Significance was accepted at $p < 0.05$. Effect sizes (ES) were calculated for performance related data, with ESs of <0.2 classified as small, 0.4 to 0.6 as medium, and >0.8 as large (Cohen, 1988). Data are presented as mean ± SD unless otherwise stated.

3 Results

3.1 Physical Overload of the Tour de France ride vs Training

Mean ride time in training was 1.67 ± 0.35 hours compared to 6.8 ± 2.2 hours for the Tour de France (P<0.0001). Mean distance per ride was greater in the Tour de France (166.5 ± 56.1 km) vs training (41 ± 11 km; P<0.0001) and equated to a 305% increase in distance per ride. Total work done per ride was also greater in the Tour de France (3743 ± 994 kJ) vs training (965 ± 280 kJ; P<0.0001), equating to a 287% increase.

3.2 Performance Data

3.2.1 Power Data

There was an effect of stage on average power ($F_{(2,18)} = 16.4$; P<0.0001) with a linear decline in average power evident from stage 1 (156 ± 19 W) to stage 21 (91 ± 12 W; P<0.0001). Average power was higher for intermediate (144 ± 16 W; P<0.01; ES = 0.25) and mountain stages (151 ± 15 W; P<0.0001; ES = 0.64) compared to flat stages (139 ± 22 W). There were no differences between intermediate and mountain stages (P=0.8986).

Normalised Power (NP) was significantly different among stage types (F(2, 18) = 21.12; P<0.0001) and showed a linear decline across stages (P<0.0001, Figure 1). NP was higher for intermediate (187 ± 7 W; P<0.001, ES = 2.2) and mountain stages (195 ± 7 W; P<0.0001; ES = 2.9) compared to flat stages (161 ± 15 W). There was no difference between intermediate and mountain stages (P=0.3490).

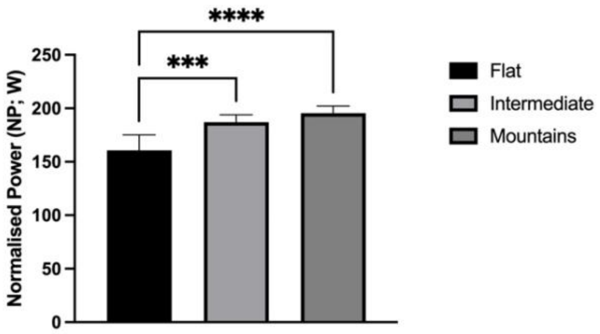

Figure 1. Normalised power based on stage type.
*** denotes difference between flat and intermediate stages (P<0.001). **** denotes difference between flat and mountain stages (P<0.0001).

Maximum power achieved was different between stages (F(2, 18) = 2.78; P<0.0001) and showed a linear decline from stage 1 (828 ± 205 W) to stage 21 (718 ± 127 W, slope = -6.860, P<0.0001).

As a percentage of total time, 69 ± 9.0% was spent in power zone 1, 12.5 ± 5.1% in zone 2 (moderate domain), 10.6 ± 3.8% in zone 3, 3.8 ± 1.2% in zone 4 and 1.9 ± 0.8% in zone 5 (severe domain), and 2.1 ± 0.6% above zone 5 in the extreme intensity domain (Figure 2A). The distribution of time spent in the five zones was not different among stages (P=0.99), but there was a difference in time spent in zone within stages (F(6, 105) = 2070; P<0.0001, Figure 2B). Furthermore, there was a stage *x* zone interaction effect (F(12, 105) = 21.5; P<0.0001), where the total time spent in zones 1 and 2 was greater in stage 21 compared to stage 1 (P<0.0001). There was an interaction effect of stage type on the percentage of time spent in zone (P<0.0001).

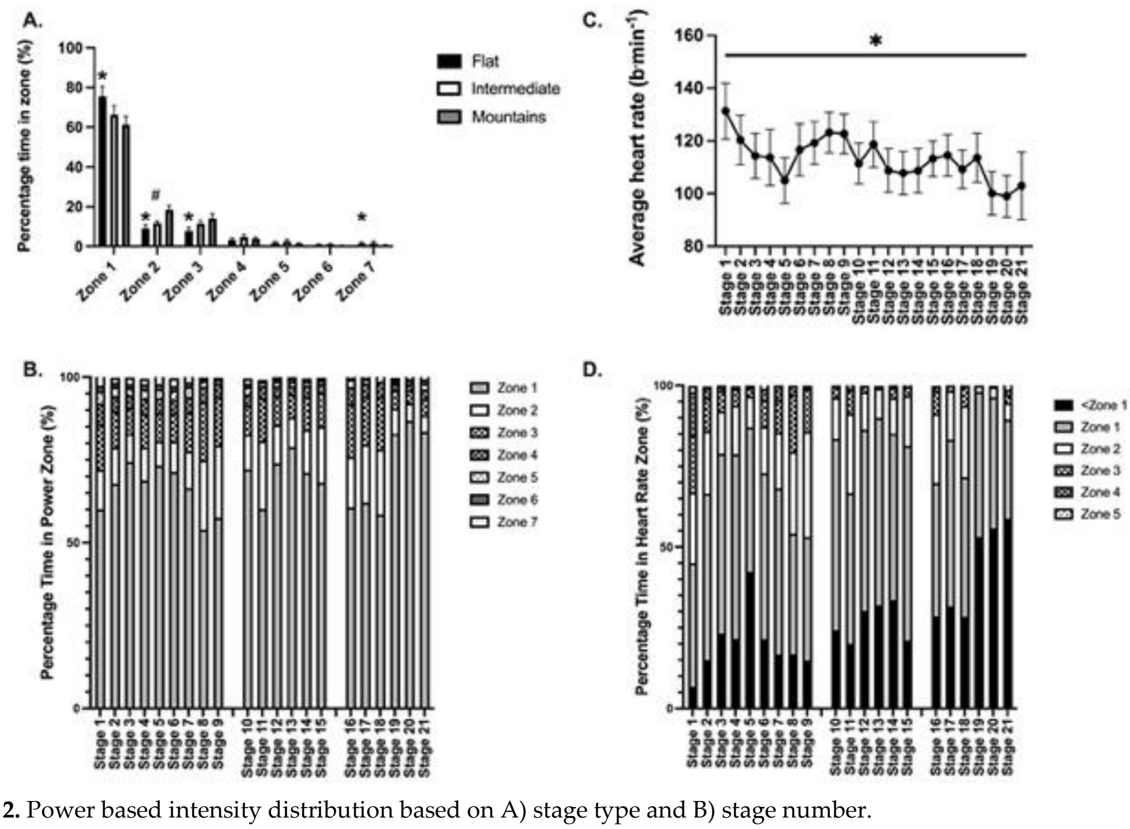

Figure 2. Power based intensity distribution based on A) stage type and B) stage number.
* denotes difference between flat and intermediate stages (P<0.0001), # denotes difference between flat and mountain stages (P<0.0001). For each of the 21 stages C) average heart rate D) percentage time in heart rate zones. * denotes a significant effect of stage on average power or heart rate (P<0.05).

3.2.2 Heart Rate

As a percentage of total time, 76.5 ± 14.1 % was spent in HR zone 1, 15.4 ± 7.7 % in zone 2, 6.1 ± 5.3% in zone 3, 1.8 ± 2.9% in zone 4 and 0.2 ± 0.5 % in zone 5 (figure 3). There was an effect of stage on average HR ($F(20,255) = 42.3$; $P<0.0001$) with a reduction in average HR evident from stage 1 (131 ± 10 bpm) to stage 21 (103 ± 13 bpm; figure 2C). The decline in average HR was linear ($r= -0.8926$, $P<0.0001$). Similarly, there was a decline in the max HR achieved from stage 1 (169 ± 10 bpm) to stage 21 (153 ± 7 bpm, $P<0.0001$), which was also linear in nature ($r=-0.8719$, $P<0.0001$). There was an interaction between stage number and HR zone distribution ($F(100,1520) = 17.5$; $P<0.0001$) with an increase in the percentage time spent in zone 1 from stage 2 onwards (figure 2D). Stage type had an impact on the percentage of time spent in each HR zone, with an interaction effect among stage type and time in zone ($F(8, 40) =7.18$; $P<0.0001$). More time was spent in zone 1 on flat stages compared to both intermediate and mountain stages (both $P<0.0001$, figure 2D). Similarly, more time was spent in zone 2 on mountain vs flat stages ($P<0.001$).

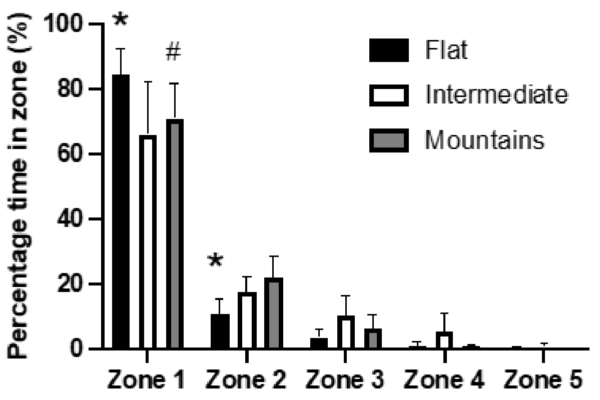

Figure 3. Heart rate distribution based on stage type.
* denotes difference between flat and intermediate stages ($P<0.0001$); # denotes difference between flat and mountain stages ($P <0.0001$).

3.2.3 Work Done

Mean work done for each stage was 3441±1342 kJ and equated to 20±5 $kJ \cdot km^{-1}$. There was an effect of stage type on total work done (range 484 ± 56 kJ to 5589 ± 591 kJ, $F(2, 18) = 10.6$; $P<0.0005$). Work done was different between flat (2469 ± 1165 kJ) and intermediate stages (4229 ± 420 kJ; $P<0.005$ ES = 2.0), flat and mountain stages (4701 ± 736 kJ, $P<0.0001$; ES = 2.3) but not between intermediate and mountain stage ($P=0.43$).

3.2.4 Training Load

Mean Training Stress Score® was 275 ± 116 AU and equated to a $TSS \cdot Km^{-1}$ of 1.64 ± 0.5 AU. There was an effect of stage on TSS ($F(2, 18) =17.0$; $P<0.0001$, figure 4A). TSS was higher for both intermediate (343 ± 50 AU; $P<0.0005$ ES = 2.6) and mountain (377 ± 46 AU; $P<0.0001$; ES = 3.3) stages compared to flat stages (210 ± 51 AU). When normalised to distance ($TSS \cdot Km^{-1}$), there were differences in flat compared to both intermediate ($P<0.005$) and mountain ($P<0.0001$) stages, as well as intermediate vs mountain stages ($P<0.0005$, figure 4B). Consequently, Intensity Factor® was higher for intermediate (0.663 ± 0.029; $P<0.001$) and mountain stages (0.693 ± 0.022 AU; $P<0.0001$) compared to flat (0.587 ± 0.045 AU) stages, with no differences between intermediate and mountain stages ($P=0.232$). To isolate the impact of cumulative fatigue on TSS, TSS was compared between two flat stages in week 1 (stage 3) and week 3 (stage 19). There was a clear difference in TSS among the two stages (245 ± 51.7 vs 190 ± 36.5; $P<0.005$; ES = 1.2). When normalized to distance $TSS \cdot Km^{-1}$ was 1.28 ± 0.24 for stage 3 and 0.91 ± 0.19 for stage 19 ($P<0.0001$).

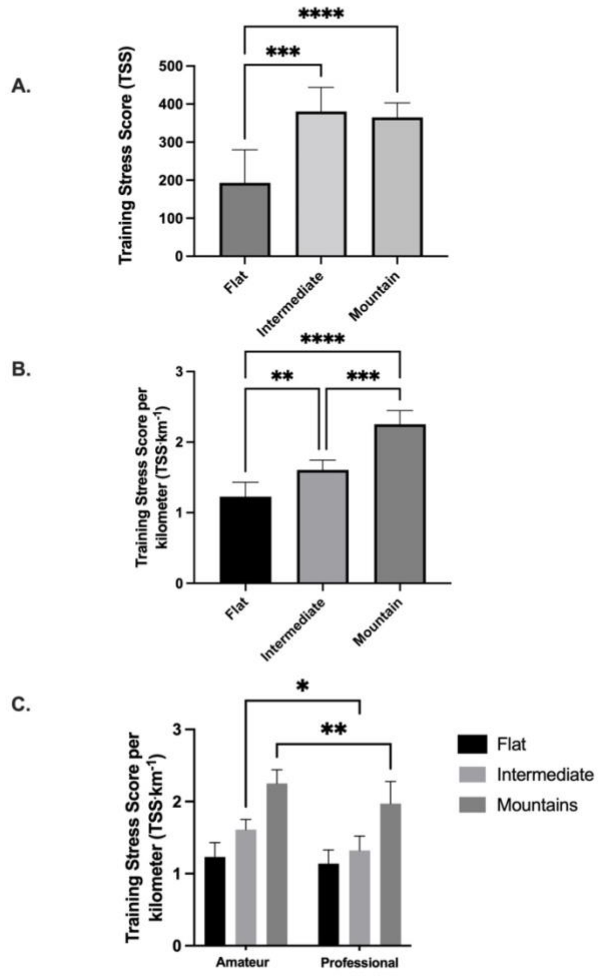

Figure 4. The training stress score™ (TSS™) was dependent on stage type (A) and this persisted when TSS™ was normalised to distance (B). Panel (C) shows profession vs amateur comparison on TSS·km^{-1} *<P<0.05; **P<0.005; ***P<0.001; ****P<0.0001

3.3 Perceptual Data

3.3.1 Rating of Perceived Exertion

Mean stage RPE was 13 ± 3 AU. There was an effect of stage type on RPE (Figure 5; F (2,18) =18.81; P<0.0001) with RPE higher for intermediate (14 ± 1 AU; P<0.01) and mountain (16 ± 1 AU; P<0.0001) stages compared to flat (12 ± 1 AU) stages. When comparing similar stages at the start and end of the Grand Tour, RPE was higher for stage 3 compared to stage 19 (12 ± 1 vs 11 ± 3; P<0.05).

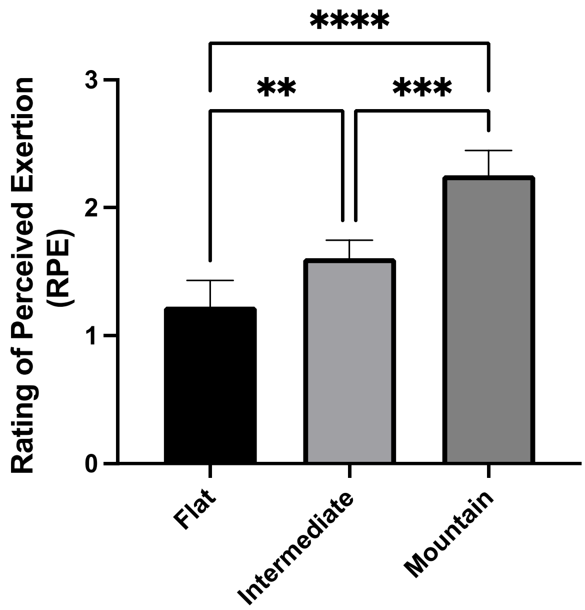

Figure 5. Rating of Perceived Exertion (RPE) was dependent on stage type, with both intermediate and mountain stages being perceived to be harder than flat stages. There were no differences between intermediate and mountain stages. **P<0.005; ****P<0.0001.

3.3.2 Sleep and Tiredness

Self-reported sleep duration was 6.34 ± 0.42 hours and did not change throughout the 21 stages (P=0.51). There was no effect of stage type on sleep duration (P=0.83), reflecting that reported tiredness (42 ± 4 AU; P=0.50) and quality of sleep remained unchanged throughout the event (47 ± 6 AU; P=0.55). The stable sleep data was reflected in unchanged morning tiredness throughout the duration of the event (P=0.50. Neither sleep duration, nor sleep quality were correlated to any other performance or perceptual variables.

3.3.3 Muscle Soreness

Over the 21 stages, mean self-reported muscle soreness was 28.3 ± 7.8 AU and this did not change over the course of the event (Figure 6; P=0.06). There was an effect of stage type on self-reported muscle soreness the following morning (P<0.05). Increased muscle soreness was reported following mountain stages compared to flat stages (33.7 ± 19.5 AU vs 25.8 ± 18.6 AU; P<0.05) with no difference between flat and intermediate (P=0.14), nor between intermediate and mountain stages (P=0.77). Muscle soreness was correlated to tiredness (r=0.617, P<0.005).

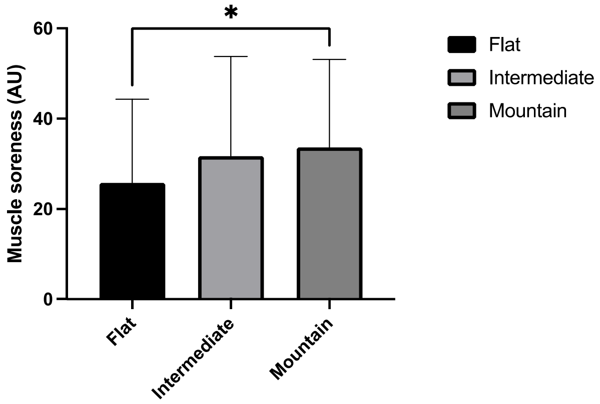

Figure 6. There were differences in post stage muscle soreness for flat compared to mountain stages, where mountain stages elicited a greater perception of muscle soreness the following day. * denotes P<0.05.

There were no differences within stage during the event for nausea (P=0.47), abdominal discomfort (P=0.85), gut fullness (P=0.66), bowel urgency (P=0.20), diarrhoea (P=0.59) and vomiting (P=0.39). There were however differences among stages to belching frequency (P<0.05) and flatulence (P<0.0005). Abdominal discomfort was correlated to stage TSS (r=-0.588, P<0.005), total energy intake (r=-0.525, p<0.05) and diarrhoea (r=0.670, P<0.005).

Total mood disturbance significantly changed throughout the duration of the event (P<0.05; figure 7A, N=6). Mood disturbance increased from pre-event to rest-day 1 and rest-day 2, and then reduced following the event. There was no difference in Tension-Anxiety (P=0.08), Anger-Hostility (P=0.08), Vigour-Activity (P=0.62) and Confusion-Bewilderment (P=0.52) throughout the event. However, Depression-Dejection and Fatigue-Inertia changed significantly over the course of the event (P<0.05). Specifically, Depression increased from pre-event to rest-day 1 and rest day 2, and then reduced following the event (figure 7B), whereas Fatigue increased from pre-event to rest-day 1, and then reduced across rest day 2 and following the event (figure 7C).

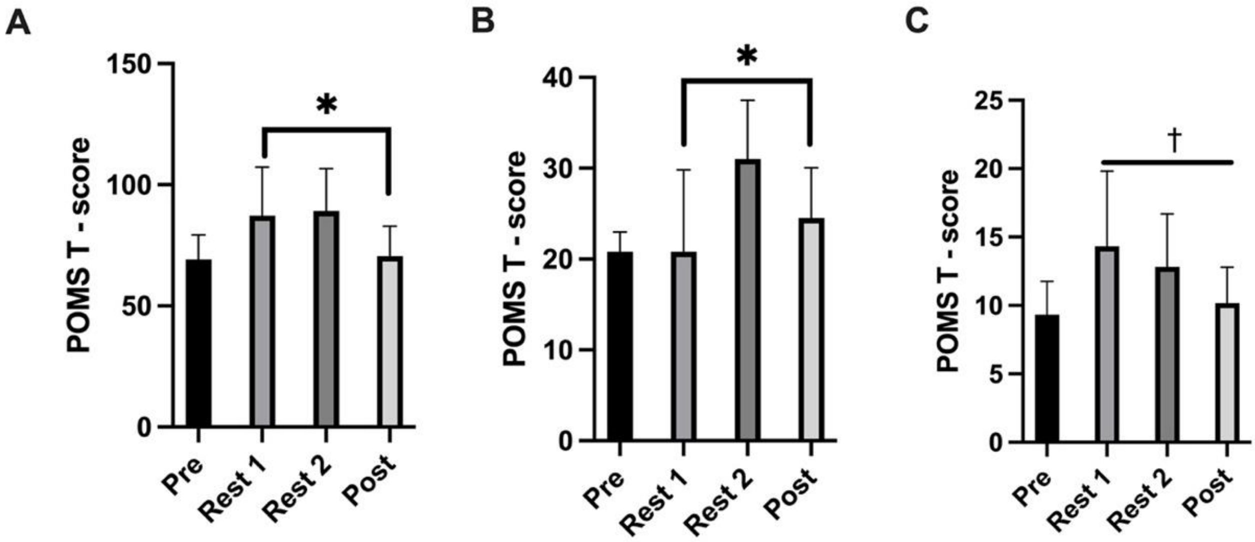

Figure 7. Profile of Mood States altered throughout the 21 days of the Grand Tour (N=6). A) Shows changes in mood disturbance from rest day 1 to the day after the final stage. B) There was an increase in symptoms of depression from the start of the event to the first and second rest days, which was reduced on completion of the final stage. C) An increase in mental fatigue was evident by rest day one, and this remained elevated throughout the Tour compared to pre-Tour. *= denotes. P<0.05. † denotes a difference compared to Pre (P<0.05)

3.4 Professional vs Amateur

There were main effects when comparing professional riders and the amateur riders in the present study for training status (P<0.05) and stage type (P<0.0001) and a significant interaction effect (P<0.005) on TSS. TSS was higher for amateur riders on intermediate stages ($P<0.001$; ES = 2.4) but was not different on mountain stages (P=0.15) or flat stages (P=0.27). There were main effects for training status ($P<0.0005$) and stage type ($P<0.0001$) on TSS·km^{-1} (figure 4C). TSS·km^{-1} was higher for amateur riders in both the mountains ($P<0.005$; ES = 0.95) and on intermediate stages ($P<0.05$; ES = 1.5) compared to professionals, with no difference in flat stages (P=0.284). Total work done was different between professionals (3223 ± 350 kJ) and amateurs (3743 ± 994 kJ; $P<0.0005$; ES = 0.8). With total work done per kilometre being greater for professional (26.2 ± 2.9 kJ·km^{-1}) vs amateur (20.1 ± 5.0 kJ·km^{-1}; $P<0.0001$; ES = 2.0). Mean RPE was lower for amateur (13 ±3 AU) vs professional riders (16 ± 1 AU; $P<0.0001$).

4 Discussion

The aim of this investigation was to determine the physiological impact of riding a Grand Tour route on trained amateur cyclists. Based on HR data, we show that a decline in average and max heart rates were apparent following only 4 stages of the route, indicating that the riders were likely experiencing a degree of autonomic dysfunction (Bosquet, Merkari, Arvisais, & Aubert, 2008) and cardiac fatigue (Scott & Warburton, 2008) because of a rapid and sustained increase in chronic load. This is supported by the increased percentage of time spent in zone 2 and below, and an inability to reach near maximal heart rates which was increasingly evident as the Tour de France progressed. When paired with a similar blunted response in mean and maximum power, these data show that sympathetic withdrawal was evident from the early stages of the Tour de France and is indicative of significant overreaching of riders.

The 21 days of intensified exercise in the current study could have led the cyclists into a state of NFOR, reducing physical performance, which may not recover for several weeks (Meeusen et al., 2013b). Signs of overreaching have been reported to occur within as short as 7 days of intensified training with limited recovery (Halson et al., 2002c). This view is supported by a decline in submaximal power and heart rates throughout the event. A decline in maximum HR was shown with maximum HR dropping by more than 10 beats per minute in the final week compared to the first week, despite several mountain stages. A reduction in maximum HR has been suggested to be indicative of acute over-reaching after a period of more than two weeks of intensified training (Bosquet et al., 2008). Such a decline in maximum HR is likely a consequence of reduced sympathetic nervous system activity and lower sensitivity to catecholamines following a period of intensified training (Meeusen et al., 2013a). We clearly show that the total distance of each stage in the Tour de France was more than 300% of a typical training ride, with total work done being elevated by a comparable magnitude. These data give support that the 21 stages of the Tour de France represented a significant physical overload in the cohort, which was more than enough to elicit the effects of NFOR we report.

Reimers et al. report in their systematic review with meta-analysis examining the effects of exercise on the resting HR a lowering of resting HR in endurance trained males and females following periods of intensified exercise ranging from 4 to 52 weeks(Reimers, Knapp, & Reimers, 2018). It has been shown that β-adrenoreceptor density on mononuclear cells from peripheral blood samples can be lower in young, regional/national level long-distance runners and swimmers in a 5-6 week period of heavy training when compared to non-trained controls (Jost, Weiß, & Weicker, 1989). In addition, the endurance runners showed a lowered β-adrenoreceptor reactivity and plasma catecholamine concentrations alongside a lowered resting HR. However, this lowering of HR following periods of intensified exercise may be due to a decrease in the intrinsic HR and not an increased parasympathetic tone or decreased responsiveness to beta-adrenergic stimulation (Bahrainy, Levy, Busey, Caldwell, & Stratton, 2016). The data from the current study suggests that the intensified exercise over the course of the 21 days may have led to reduction in β-adrenoreceptor reactivity leading to a reduced HR.

Although we do not report any changes to sleep habits during the Tour de France compared to the preceding month's self-reported sleep, it is possible that the amount of sleep reported in the present cohort was insufficient to promote optimal recovery among stages. In elite level athletes, it is advised they get at least 8 hours of restful sleep a night, with a growing body of literature showing that impaired sleep results in hindered recovery from exercise (Halson, 2008) and impaired mood (Mah, Mah, Kezirian, & Dement, 2011). In a study of elite athletes, it has been reported that they achieve approximately 8.5 hours in bed per night, but only 7 hours of sleep (Leeder, Glaister, Pizzoferro, Dawson, & Pedlar, 2012). Therefore, it is highly likely that the self-reported data in the present cohort does not reflect the actual time asleep. Consequently, the relatively short time spent sleeping in this group will also have hindered recovery and may contribute to the appearance of symptoms commonly associated with intensified training and NFOR.

The Profile of Mood States questionnaire has been used as a tool in athlete monitoring during periods of intensified training (Raglin & Morgan, 1994). Consistent with the present data, an elevation in mood disturbance is commonly linked with intensified training. Furthermore, when the individual facets of mood disturbance are considered, increases in depression are the most distinct in those athletes displaying symptoms of over-training syndrome, with as many as 80% of athletes displaying symptoms of clinical depression (Morgan, O'Conner, Sparling, & Pate, 1987). In relation to the present data, the absolute change in depression is less than that previously shown in over training syndrome, however it still exceeds a change associated with 'healthy' athletes following a period of intensified training. This suggests that the present cohort was displaying characteristics closely aligned with NFOR.

The comparison of TSS, TSS·km^{-1} and RPE between stage 3 and stage 19, is an attempt to consider the cumulative effect of fatigue on the total physiological strain of the riders. Both stages occur 3 days following a rest day and were of similar distance and duration. We report a reduction in both indicators of training stress for stage 19 compared to stage 3, with RPE also being lower. This is perhaps contrary to what we expected, in that it was anticipated these metrics would in fact be higher towards the end of the three weeks. However, given that TSS is based on relative power, the fact that we show that riders' power output declines throughout the course of the three weeks, it is no surprise that TSS was also lower. However, it is interesting to note the same pattern in RPE. RPE, and session RPE as reported here, is a valid and reliable indicator of total training load (Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017) and accounts for both intensity (a combination of internal and external load) and duration of training. The question for the present data is whether load was reduced owing to increased fitness due to acute over-reaching, or because of altered function of the central and peripheral nervous systems in the face of extreme fatigue. Owing to the suppression in mean HR, and the assumed association with impaired autonomic nervous system function, the change in TSS and RPE reflects the latter. It is possible that the reduction in mean power, reflects a failure in muscle recruitment owing to changes in sensitivity to catecholamines and activation of larger motor units.

Taken together, these data support the view that the participants experienced a disturbance in their autonomic nervous system, which resulted in broad symptoms consistent with NFOR and over-training. Recovery from this is likely to have taken several weeks to months (Meeusen et al., 2013a), however, it was beyond the initial scope of this study to conduct a long term follow up with the riders.

4.1 Impact of stage type

There was an effect of stage type on the physiological demand placed on the riders. The altered distribution of power in flat vs mountain stages reflects the higher torque and power demand on climbs experienced by the riders. An increase in power is likely driven by an increase in torque during uphill cycling (Bertucci, Grappe, Girard, Betik, & Rouillon, 2005), which arises primarily because of a reduced cadence. This is particularly the case at gradients above 8% and appears to be because of increased muscle activation (Arkesteijn, Jobson, Hopker, & Passfield, 2013) to meet power and torque demands. An additional benefit of increased torque due to a lower cadence may be a reduction in energy cost of cycling at a lower cadence, allowing more work to be done per molecule of ATP (Ferguson et al., 2001). It is possible that riders adopt a lower cadence to optimise the efficiency of prolonged riding uphill at relatively high power. This may also be especially true for the older cohort in this group who typically have a higher density of type I muscle fibres (Harridge, Magnusson, & Saltin, 1997; Korhonen et al., 2006), which may be more resistant to fatigue at lower cadences. Furthermore, time spent at higher powers during mountain stages, likely resulted in significant muscle damage in type 1 muscle fibres (Koller et al., 1998) and elevated RPE (Twist & Eston, 2009), which is reflected in the present RPE and muscle soreness data.

4.2 Amateur vs Professional

The HR distribution appears markedly different to that reported in professional riders during a Grand Tour (van Erp & Sanders, 2020). Grand Tour riders, typically spend more time in HR zone 3 and above (~53%) than the present cohort. This difference likely reflects both the competitive nature of a professional Grand Tour compared to the present cohort's Tour de France, but also the increased fractional utilization (Costill, Thomason, & Roberts, 1973; Coyle et al., 1991) and capability to sustain relatively higher powers for prolonged periods of time evident in professional riders. In the present cohort, more than 80% of total ride time was spent in either power zone 1 or 2, and less than 7% of time above lactate threshold power (zone 4 and above). Whereas professional riders spend less time in zones 1 and 2, and ~20% of race time in zone 4 and above (van Erp & Sanders, 2020), reflecting a far higher $\dot{V}O_{2max}$, CP and fractional utilization in the World's best male professionals compared to a group of well-trained amateurs. This difference may also be compounded by the difference in mean age of professional riders vs our present cohort who may experience greater autonomic dysfunction as a result of ageing (Wichi, De Angelis, Jones, & Irigoyen, 2009). However, regular physical exercise throughout the lifespan is believed to at least reduce and maybe prevent the age related decline in cardiovascular autonomic function (Wichi et al., 2009). Therefore, it is difficult to conclude whether this differences due to the nature of the event, ageing or physical capacity of the two groups.

In comparison to data obtained from the World Tour (van Erp & Sanders, 2020), the present data show that despite the lower absolute power, the total work done by the amateur cohort was higher than reported previously for professional Grand Tour riders. This is largely due to the increase in duration, as the relative work done per kilometre was lower in the amateur group. In the professional cohort, speed and power is higher, resulting in elevated oxygen uptake, meaning they can sustain much higher absolute power outputs over a given distance and duration. Furthermore, professional riders will likely have a higher gross efficiency which can explain up to 30% of the variation in power output between groups (Jobson, Hopker, Korff, & Passfield, 2012). Practically, this indicates that total daily energy expenditure is likely higher for amateur riders and this needs to be accounted for if athletes are to avoid acute/chronic energy deficit and glycogen depletion during such events which can lead to over-training (Meeusen et al., 2013b).

It must be acknowledged that the comparisons made are somewhat challenging owing to the discrepancy in both inherent physiology and also training status. It is clear that the amateur cohort was sub-optimally prepared for the event where the aim was completion and not competition. This will undoubtedly have place greater physiological strain on them given the significant overload in training load, whereas the professional group is more accustomed to multiday, high volume endurance training and racing. For this reason, it is likely that some of the differences reported, are due to marked physiological differences between groups (e.g. CP and therefore $\dot{V}O_2$ max, economy etc.) which are compounded by the relative training status of both cohorts.

5 Practical Applications

The completion of extreme endurance events among well-trained yet amateur athletes is increasingly common. These data show that coaches and athletes need to consider the specific physiological demands that these events place upon amateur athletes. Of particular note is that multi day events often represent a significant overload to an amateur's habitual training load and can rapidly cause the onset of symptoms associated with NFOR. This should then be accounted for during the event to ensure that intensity remains relative to the physiological state of the athlete as they accumulate more fatigue. From a training perspective, riders and coaches should aim to avoid the traditional three day block periodization commonly used, and focus on extending block of work to 5-7 days which reflect the spacing of time trial and full rest days on a Grand Tour. This will ensure that they are more appropriately prepared for the back to back days of high workload.

Perhaps most importantly, athletes should be aware of the increase in energetic demand of completing a Grand Tour, as often recommendations are based on single day, professional events. To lessen the impact of energy deficit on performance potential and risk of NFOR, it is imperative that athletes consume sufficient energy to meet demand, and this should be trialled in training during periods of high training load.

A clear limitation of this study is that the data are somewhat based on field collected and self-report data. Despite this, the calculations used are all well established in the scientific literature and all participants were familiarised with the data collection protocols prior to the event. Furthermore, one of the authors (SF) was present throughout the event and able to assist with data collection. The power and heart rate zone calculations are also based on a training derived critical power, which may not wholly reflect a rider's capacity. However, given that this study was conducted in 2020/21, it was not possible to conduct in depth laboratory trials owing to the COVID-19 pandemic. Furthermore, there is a stark contract between the mean age of the present cohort and that of the professional peloton who are typically in their mid 20s to early 30s. This will clearly limit some of the comparisons made in the present paper, owing to age related declines in aerobic fitness, heart rate and impaired recovery amongst other factors. However, we believe that the comparison is still warranted and of interest to those considering a similar physical challenge as an athlete, or to help inform coaching/training decisions made by coaches assisting riders in preparing for such events in the future.

6 Conclusions

These data provide a unique insight into the physiological and psychological impact of a cohort of trained amateur athletes riding the same 3,500 km course of the Tour de France as the professional riders. The Tour de France represented a significant overload for the cohort compared to the training completed in the preceding 6 months, with daily load on the Tour de France, representing a 300% increase on what was typically experienced during training. The data show that after 4-5 days, there is evidence of altered autonomic nervous system function, with a progressive decline in both mean and average HR throughout the 21 stages. This is supported by the associated change in HR distribution, with a shift towards zones 1 and 2 (moderate intensity domain) and reduced time in zones 4 and 5 (heavy to severe intensity domains) as the ride progressed. Similar data relating to power, which may indicate alterations to both central and peripheral activation of motor units, resulted in a decline in average and maximum power. These data likely reflect the training status of the riders, who would be limited in their endurance capacity compared to professional cyclists who regularly complete very high volumes of training.

It is interesting to note that compared to World Tour riders, the training stress experienced by the present cohort was comparable to that reported in the professional peloton during a Grand Tour. This would result in the amateur group riding at a much higher percentage of their overall capacity, resulting in a higher overall level of accumulated fatigue. Therefore, it is unsurprising that the cohort consistently displayed physiological and psychological symptoms of NFOR and OTS by the end of the 21 stages. Amateur participants in multi-day endurance events should be made aware of the risks, signs and symptoms of developing NFORS and adopt strategies around intensity management and recovery to maintain their performance throughout the event.

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