The Effectiveness of a 30-Week Concurrent Strength and Endurance Training Programme in Preparation for an Ultra-Endurance Handcycling Challenge: A Case Study

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Abstract

Purpose: The aim of the following case study was to evaluate the effectiveness of a 30-week concurrent strength and endurance training programme designed to prepare a trained H4 male handcyclist (aged 28 years, bi-lateral, above knee amputee, body mass 65.6 kg), for a 1,407 km ultra-endurance handcycling challenge.

Methods: This observational case study tracked selected physiological measures, training intensity distribution, and total training load over the course of a 30-week concurrent training protocol. Furthermore, the athlete's performance profile during the ultra-endurance challenge was monitored with power output, cadence, speed, and heart rate recorded throughout.

Results: Findings revealed considerable improvements in power output at a fixed blood lactate concentration of 4 mmol·l^{-1} (+25.7%), peak aerobic power output (+18.9%), power-to-mass ratio (+18.3%), relative $\dot{V}O_{2peak}$ (+13.9%), gross mechanical efficiency (+4.6%), bench press 1RM (+4.3%), and prone bench pull 1RM (+14.9%). The athlete completed the 1,407 km route in a new handcycling world record time of 89:55 hrs. Average speed was 18.7 ± 2.1 km·hr-1; cadence averaged 70.0 ± 2.6 rpm, whilst average PO was 67 ± 12 W. In terms of internal load, the athletes average heart rate was 111 ± 11 b·min-1.

Conclusion: These findings demonstrate how a long-term concurrent strength and endurance training programme can be used to optimise handcycling performance capabilities in preparation for an ultra-endurance cycling event. Knowledge emerging from this case study provides valuable information that can guide best practice with respect to handcycling training for ultra-endurance events.

Keywords: Paralympic Sport; Handbiking; Upper Body Strength; Endurance; Arm Ergometry.

Introduction

Handcycling is a competitive and recreational sport undertaken by individuals who are unable to ride a conventional road bike or tricycle due to a spinal cord injury (SCI) and/or other physical impairment of the lower limbs. Handcycling has been a Paralympic Games event since 2004[26] however, despite the sport's increased popularity, a paucity of scientific information exists with respect to the preferred approach by which to develop handcycling performance capabilities. As with many Paralympic sports, handcyclists tend to be relatively heterogeneous in terms of their age, performance level, and physical disability. Therefore, knowledge that stems from applied case studies provides valuable information to help guide best practice within this exciting and liberating Paralympic sport.

While the majority of trained handcyclists compete in organised road races and time trials, others focus their attention on personal challenges, including organised sportive events and/or ultra-endurance challenges. Within the United Kingdom, the highly respected John O'Groats to Land's End (JOGLE) challenge has a long tradition within the cycling community, representing an alternative to the popular Land's End to John O'Groats (LEJOG) route. The route covers 1,407 km and involves over 11,000 m of ascent. Previously, Abel et al.[2] reported on an elite H3 male handcyclist who trained for and completed the ultra-long Styrkeprøven cycling race in Norway. The athlete completed the 540 km race in a total time of 38:52 hrs, climbing over 4,200 m whilst maintaining an average speed of 21.6 $km \cdot h^{-1}$. This case study demonstrated that, through considered and appropriate training, handcyclists can successfully complete ultra-endurance cycling challenges.

In the context of handcycling performance, power output at a fixed blood lactate concentration of 4 $mmol \cdot l^{-1}$ (PO_4), relative VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$), peak aerobic power output (PO_{peak}), power-to-mass ratio ($W \cdot kg^{-1}$), and gross mechanical efficiency (GME) have all been identified as significant predictors of handcycling performance.[1,6,12,13,16,17,18] Therefore, the following case study tracked the aforementioned physiological measures prior to, during, and upon completion of a 30-week, concurrent training programme. Furthermore, measures of upper body strength, maximum anaerobic power ($PO_{max,AO15}$), and anaerobic power reserve (APR) were also monitored. The intensity and duration of a training stimulus fundamentally drives physiological adaptation. Indeed, the monitoring, and quantification of training stimuli is recognised as an important factor in the long-term development of endurance athletes, including handcyclists.[29] Consequently, the present study tracked the athlete's training intensity distribution (TID), and total training load (TTL). Finally, this study also communicates the performance profile of the athlete during the ultra-endurance JOGLE cycling challenge.

Methods

Participant

The focus of this case study is a male handcyclist aged 28 years (bi-lateral, above knee amputee, UCI classification H4, body mass 65.6 kg). The athlete had more than three years of handcycling-specific training and competitive race experience. He also had previous ultra-endurance cycling experience, having completed the 4828 km Race Across America as part of an eight-man relay team in June 2017. He reported no upper body musculoskeletal injuries that could affect his performance prior to the study. All procedures employed were conducted in accordance with the declaration of Helsinki with approval granted by the Research Ethics Committee of Buckinghamshire New University, High Wycombe, United Kingdom. Prior to any testing being completed, the handcyclist provided written informed consent.

Design

This 30-week observational study commenced in November 2018 and tracked selected physiological measures, TID, TTL, and the performance profile of a trained handcyclist during a recognised, ultra-endurance cycling challenge. To provide comparative, baseline data, laboratory testing took place on three different occasions during weeks 1, 15 and 30. Testing was completed over two consecutive days: graded exercise test (GTX), and 15-s all-out sprint test (day 1); and 1 repetition maximum (1RM) strength testing (day 2). A period of 24-hours separated testing sessions in order to limit the impact of fatigue. Before testing, the athlete abstained from strenuous exercise and refrained from consuming caffeine and alcohol for at least 48 hours. All testing occurred indoors, under controlled environmental conditions (18° C, 50 – 60% relative humidity). Finally, during the JOGLE PO, cadence, speed, and heart rate parameters were continually monitored.

Graded Exercise Test

For all laboratory testing, training, and racing, the participant used his own hand bike (Carbonbike, St. Petersburg, USA). For both the GTX and 15-s all-out sprint tests, the participant's hand bike was fitted to a standard, indoor cycling turbo trainer (Fluid 2, CycleOps, Madison, WI, USA). Measurements of PO were made using an SRM PowerMeter (Schoberer Rad Messtechnik, Julichm, Germany, ±1% accuracy, sample frequency 1000 Hz) installed in the crank. The SRM is an accurate and reliable instrument used to measure PO whilst cycling,[20] and was zero-off set prior to use in accordance with the manufacturer's instructions. Power (W) and heart rate (HR) was logged using a commercially available receiver (Garmin Edge 1010, Garmin Ltd, Olathe, KS, USA). In addition to PO and HR, oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation (VE), and respiratory exchange ratio (RER) were continuously monitored using a calibrated, online gas analysis system (Oxycon Pro, Jeager, Warwick, Warwickshire, UK).

Following a 10-min warm-up at a self-selected PO, the test protocol started at a work rate of 40 W with subsequent 20 W increments every 5-mins until the required PO could no longer be maintained, or until the participant reached volitional exhaustion. Values of VO_{2peak} and PO_{peak} were identified as the highest PO and peak oxygen consumption achieved during the last fully completed 30-s. Throughout the test, the participant was free to adjust his gear ratio and/or crank rate as needed in order to maintain the required power output. Every 5-mins and upon immediate completion of the test, the participant was asked to indicate his global rating of perceived exertion (RPE) using a 6 to 20 Borg scale.[5] All respiratory parameters were calculated for breath-by-breath, subsequently, data were averaged at 1-min intervals at rest and every 30-s during each exercise stage.

At the end of each stage and at the point of volitional exhaustion, a small sample of capillary blood was collected from an earlobe to measure blood lactate concentration. These data were used to identify visually, fixed blood lactate concentrations of 2 and 4 $\text{mmol}\cdot\text{l}^{-1}$. Once collected, capillary blood samples were treated, analysed, and disposed of immediately using a fully automated analyser (Biosen C-line, EKF Diagostics, Barleban, Germany). Values of GME were calculated as the ratio of external work produced to the amount of energy expended when a fixed blood lactate concentration of 2 $\text{mmol}\cdot\text{l}^{-1}$ was reached. This metabolic parameter was selected as it represents a consistent, submaximal exercise intensity during which energy production is predominantly achieved via aerobic metabolic pathways. Metabolic energy expenditure was calculated from associated VO_2 and RER data according to Garby and Astrup.[10] A value of GME was then defined as:

Equ 1: GME = ((external work done/energy expenditure) x 100) (%).

As an approximation of anaerobic threshold, absolute values of PO corresponding to a fixed blood lactate concentration of 4 $\text{mmol}\cdot\text{l}^{-1}$ was also identified.

15-s All-out Sprint Test

Following his GTX, the participant recovered for one hour prior to completing a 15-s, all-out sprint protocol to assess anaerobic performance. The participant was requested to complete a 10-min warm up at a self-selected PO. Prior to commencement of the test protocol the participant was asked to adopt his highest gear ratio (52/12). Once the participant acknowledged that he was ready, the all-out sprint test commenced. Throughout this test, the participant was verbally encouraged to exert maximum, physical effort with the highest PO subsequently recorded. The participant's APR was established using the following equation:

Equ 2: APR (W) = $PO_{max,AO15}$ - PO_{peak} .[28]

Maximal Upper Body Strength Testing

In order to evaluate upper body strength, maximal and relative values of bench press and prone bench pull 1RM were determined. Strength testing was conducted on a specifically designed, IPC Para-powerlifting bench (Eleiko, Halmstad, Sweden)) and a prone-pull bench (Pullum Sports, Leighton Buzzard, England) using a 20 kg Olympic barbell and 450 mm diameter barbell plates (25, 20, 15 and 10 kg), 200 mm diameter barbell plates (2.5, 2.0, 1.5, 1.0 and 0.5 kg), two safety locks and two Velcro securing straps. Both bench press and prone bench pull 1RM testing was conducted in line with the protocols proposed by Haff and Triplett.[11]

Training Programme

Based upon a conjugated block periodisation model, a 30-week concurrent strength and endurance training programme was completed.[14,17] The programme was divided into two consecutive phases. Phase one (P1) consisted of 15-weeks of accumulated training, focused upon the development of aerobic capacity, GME, and upper body work capacity. Phase two (P2) was 12-weeks in length and represented the transmutation phase of the programme, whereby an increased focus was placed upon the development of anaerobic threshold and maximal upper body strength. Finally, phase three (P3), was planned to be 3-weeks in length and represented the realisation phase of the protocol. This phase consisted of a gradual tapering of TTL in order to reduce the impact of chronic fatigue and optimise physical preparedness for the JOGLE. Each phase was roughly split into 4-week mesocycles, which in turn were split into 3-weeks of accumulated TTL, followed by a recovery period in the fourth week whereby the TTL was reduced by 50%. Table 1 provides an overview of a typical training week.

*****Insert Table 1 Here*****

Training intensity was based on the conceptual 3-zone TID model proposed by Seiler[24] whereby, the PO identified at a given blood lactate level was used to guide training intensity. Based upon this model Zone 1 (Z1) was defined as low intensity training at a PO associated with a blood lactate concentration of <2 $\text{mmol}\cdot\text{l}^{-1}$; Zone 2 (Z2) was defined as moderate intensity training, performed at a PO between blood lactate concentrations of 2 $\text{mmol}\cdot\text{l}^{-1}$ and 4 $\text{mmol}\cdot\text{l}^{-1}$; Zone 3 (Z3) was defined as high intensity training, performed at a PO that resulted in a blood lactate concentration of greater than 4 $\text{mmol}\cdot\text{l}^{-1}$. Training volume was regulated using time whilst TTL was quantified using the TSS method which was calculated using the following formula: TSS = ((time x normalised power x intensity factor)/(PO_4 x 3600)) x 100.[3] Finally, upper body strength training loads were determined via the use of repetition zones matched with appropriate volume and recovery parameters in order to elicit the desired, adaptive response (*e.g.,* work capacity, maximal strength).[21,22,23]

Statistical Analysis

All data were calculated and presented as mean (±*SD*) and were analysed using Microsoft Excel (Seattle, USA).

*****Insert Table 2 Here*****

Results

Findings revealed that the 30-week concurrent training programme resulted in considerable improvements in PO_4 (+25.7%), PO_{peak} (+18.9%), power-to-mass ratio (+18.3%), relative $\dot{V}O_{2peak}$ (+13.9%), GME (+4.6%), Bench Press 1RM (+4.3%), and Prone Bench Pull 1RM (+14.9%). However, decrements in $PO_{max,AO15}$ (-8.2%) and APR (-18%) were observed. These changes are summarized in Table 2, while Figure 1 shows the improvements observed in blood lactate profile over the duration of the 30-week training intervention.

The athlete completed the 1,407 km route in a total time of 89:55 hrs with a net cycling time of 74:38 hrs. During the course of the JOGLE the athlete took a net rest time of 15:17 hrs which was broken down into 10 breaks lasting from 15 mins to 5 hrs. The total elevation gain over the course was 11,097 m. Average speed was 18.7 ± 2.1 $km \cdot hr^{-}1$; cadence averaged 70.0 ± 2.6 rpm, whilst average PO was 67 ± 12 W, which represented an average PO_{peak} percentage of 30.5%. In terms of internal load, the athletes average heart rate was 111 ± 11 $b \cdot min^{-1}$; all event data are summarised in Table 3.

***** Insert Figure 1 Here*****

***** Insert Table 3 Here*****

***** Insert Figure 2 Here*****

Discussion

The aim of the present study was to investigate the effectiveness of a 30-week concurrent strength and endurance training programme developed for a trained, H4 male handcyclist preparing for the 1,407 km JOGLE cycling challenge. In addition, this study monitored selected performance parameters during the JOGLE, quantifying and recording PO, cadence, speed, and heart rate throughout.

Previously Abel et al,[2] reported on the training regime of an elite, H3 male handcyclist preparing for a 540 km ultra-endurance cycling event. The authors reported that the athlete completed over 6,000 km of training which was organised into mesocycles of 3-weeks of accumulated training followed by a 1-week recovery period. Training intensity was defined as a percentage of PO achieved at a blood lactate threshold of 4 $mmol \cdot l^{-1}$ and a variety of different training sessions were utilised including recovery, extensive endurance, and interval training. No detailed information on the TTL and TID was reported; however, the athlete demonstrated an improvement in PO_4 of 63.8% whilst relative $\dot{V}O_{2peak}$ increased by 14.6 %. More recently Zeller et al,[29] analysed the TID and TLL of an elite, H5 female Paralympic handcyclist over 45 weeks of training using a concurrent training intervention. The athlete completed 194 handcycling training sessions covering a total distance of 10,190 km. In addition, 34 strength training sessions were completed during the first 21 weeks of the training programme. Using the 3-zone intensity scale as proposed by Seiler[24], Zeller et al,[29] reported a TID of 71.6% (Z1), 15.2% (Z2), and 13.1% (Z3) with the athlete demonstrating a 20% improvement in PO_4 and a 11% improvement in $PO_{peak.}$

In the present study the athlete completed 112 handcycling training sessions covering 6,073 km. In addition, 56 strength training sessions were completed during the 30-week training period. The TID according to the 3-zone intensity scale was 91% (Z1), 8.2% (Z2) and 0.8% (Z3) (Figure 4). In order to quantify TTL, session and weekly TSS was recorded. Despite being commonly used as a measure of TTL by able-bodied cyclists[27], to the best of the authors' knowledge, only one other study has reported TSS in handcyclists.[7] TSS is a composite number that takes into account the duration and relative PO of a training session to arrive at a single estimate of overall training load and physiological stress.[3] Average weekly TSS reported was 459.8 ± 267.2 which equated to an average session TSS of 114.9. Values of weekly training volume and TSS over the duration of the 30-week training protocol are shown in Figure 2. Overall, the present study observed a 25.7% improvement in PO_4 and an 18.6% increase in $PO_{peak.}$ These improvements are broadly similar to those observed by Zeller et al,[29] however, it should be noted that the present study was 15-weeks shorter and that the average weekly training distance was less (202.43 *vs*. 226.44 km per week). Values of TID differed as a larger overall volume of training was spent in Z1 (91 *vs.* 71.6%), and the total number of strength training sessions completed was considerably greater (56 *vs*. 34). However, these discrepancies are easily explained by differences in the distinct training objectives of our H4 handcyclist who was preparing for an ultra-endurance challenge whereas the H5 athlete reported by Zeller et al.[29] was preparing for shorter distance, higher intensity competitive road races and time trials.

***** Insert Figure 3 Here*****

Several authors have suggested that a TID of 80% Z1 and 20% Z2/3 may result in the optimal development of endurance performance.[24,25] This model has been described as polarized training whereby an emphasis is placed upon a large volume of low intensity training.[4] Findings of the present study support the use of a polarized approach for the development of ultra-endurance handcycling performance as a significant improvement in most physiological measures was observed. However, it must be noted that decrements in $PO_{max,AO15}$ and APR were seen. This was most likely due to the relatively low amount of moderate and high intensity training completed during the 30-week training programme.

****Insert Figure 4 Here****

Over the duration of the training programme the athlete completed 56 upper body strength training sessions. Upper body horizontal pulling and pushing strength has recently been shown to have a significant relationship with handcycling performance capabilities.[19] Furthermore, concurrent strength and endurance training has been shown to enhance body composition, VO_{2peak}, PO_{peak}, GME, and anaerobic capacity in several upper body dominant endurance sports.[8,9,17] Indeed, Nevin et al,[17] demonstrated that 8 weeks of concurrent training, based upon a conjugated block periodisation model, resulted in greater improvements in handcycling performance capabilities, compared to endurance training alone. Findings of the present study support the use of concurrent training for handcyclists as considerable improvements were observed in both key physiological markers and upper body strength measures. However, it must be noted, that due to unforeseen circumstances, the athlete did not complete as high a proportion of Z2 training during phase 2 as originally planned. Furthermore, the athlete was unable to apply a 3-week tapering period. As such only a 1-week taper was performed. This may have resulted in the athlete experiencing a degree of fatigue prior to the start of the JOGLE, an unwanted characteristic that future projects should avoid.

The athlete successfully achieved his objective and set a new handcycling world record time for the 1,407 km route of 89:55 hrs. The athlete maintained an average PO of 67 ± 12 W and an average speed of 18.7 ± 2.1 $km \cdot hr^{-1}$. Abel et al,[2] reported an average PO of 82.4 ± 12.2 W and speed of 21.6 ± 3.1 $km \cdot hr^{-1}$. However, in comparison to the data reported by Abel et al,[2] the JOGLE was 867 km longer. The JOGLE route also had 7,707 m more of ascent and the athlete rode for an additional 51:05 h. Therefore, cumulative physical and cognitive fatigue undoubtedly influenced our athlete's performance. Indeed, this can be seen in Figure 2 where the athlete's average PO and heart rate progressively decreased until stage 10, when a subsequent spike of improvement was demonstrated during the final stages of the challenge. During the JOGLE, the athlete reported considerable fatigue and discomfort specifically in his wrists and shoulders.

Practical Applications

Based upon the observations of the present study it is recommended that handcyclists and coaches preparing for ultra-endurance cycling events consider adopting a concurrent strength and endurance training programme based upon a conjugated block periodisation model. In terms of TID, it is recommended that a polarised approach based upon a 90% Z1, 8% Z2, and 2% Z3 distribution be adopted. If preparing for shorter duration, more intense road-races and individual TTs, one should likely place a greater emphasis upon moderate and high-intensity training in order to develop $PO_{max,AO15}$ and APR. In this context, a training TID of 70% Z1, 20% Z2, and 10% Z3 is recommended.[29] Finally, the use of TSS as a measure of TTL may also be prudent for handcyclists and warrants further scientific enquiry.

Conclusion

In conclusion, this case study demonstrates that with appropriate testing, training, and monitoring, effective preparation for a handcycling, ultra-endurance challenge can be achieved. However, it must be borne in mind that training adaptations are subject to highly variable inter-individual responses. This is especially prevalent in disability sport where athletes can display a heterogeneous mix of disabilities, leading to variations in functional capacity and performance potential. Despite this, findings of the present study are in agreement with the existing literature, and suggest that a concurrent strength and endurance training protocol, based upon a conjugated block periodisation model incorporating a polarized TID, can be used to develop handcycling performance capabilities in preparation for ultra-endurance cycling events.

Declaration of Interest

There is no conflict of interest to declare for the present article.

Word Count – 3209

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Table 1. Examples of a typical training week in each training phase (P1 accumulation, P2 transmutation, and P3 realisation)

Training Phase	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
P1	24:00 Z1 05:00 Z2 01:00 Z3 x 2	Strength Training Horizontal Push/Pull 7 x 4	Z1 120:00	Strength Training Vertical Push/Pull 7 x 4	24:00 Z1 05:00 Z2 01:00 Z3 x 2	120:00 Z1	Rest
P2	05:00 Z2 05:00 Z1 x 6	Strength Training Horizontal Push/Pull 4 x 5	240:00 Z1	Strength Training Vertical Push/Pull 4 x 5	14:00 Z1 05:00 Z2 01:00 Z3 x 3	240:00 Z1	Rest
P3	240:00 Z1	Rest	230:00 Z1	Rest	220:00 Z1	Rest	Rest

Table 2. Physiological and strength testing data

Date	November 2018	February 2019	June 2019
Body Mass (kg)	65.6	64.4	65.8
Peak Heart Rate (b·min^{-1})	184	182	186
Relative VO$_{2peak}$ (ml·kg-^{1}min^{-1})	46.7	51.5	53.2
PO$_{peak}$ (W)	185	200	220
Power-to-Mass Ratio (W·kg^{-1})	2.8	3.1	3.3
GME (%)	15.3	15.6	16.0
PO$_4$ (W)	140	145	176
PO$_{max,AO15}$ (W)	695	559	638
APR (W)	510	359	418
Bench Press 1RM (kg)	115.0	118.0	120.0
Relative Bench Press Strength (kg·kg^{-1} body mass)	1.75	1.83	1.82
Prone Bench Pull 1RM (kg)	87.0	90.0	100.0
Relative Prone Bench Pull Strength (kg·kg^{-1} body mass)	1.33	1.40	1.52

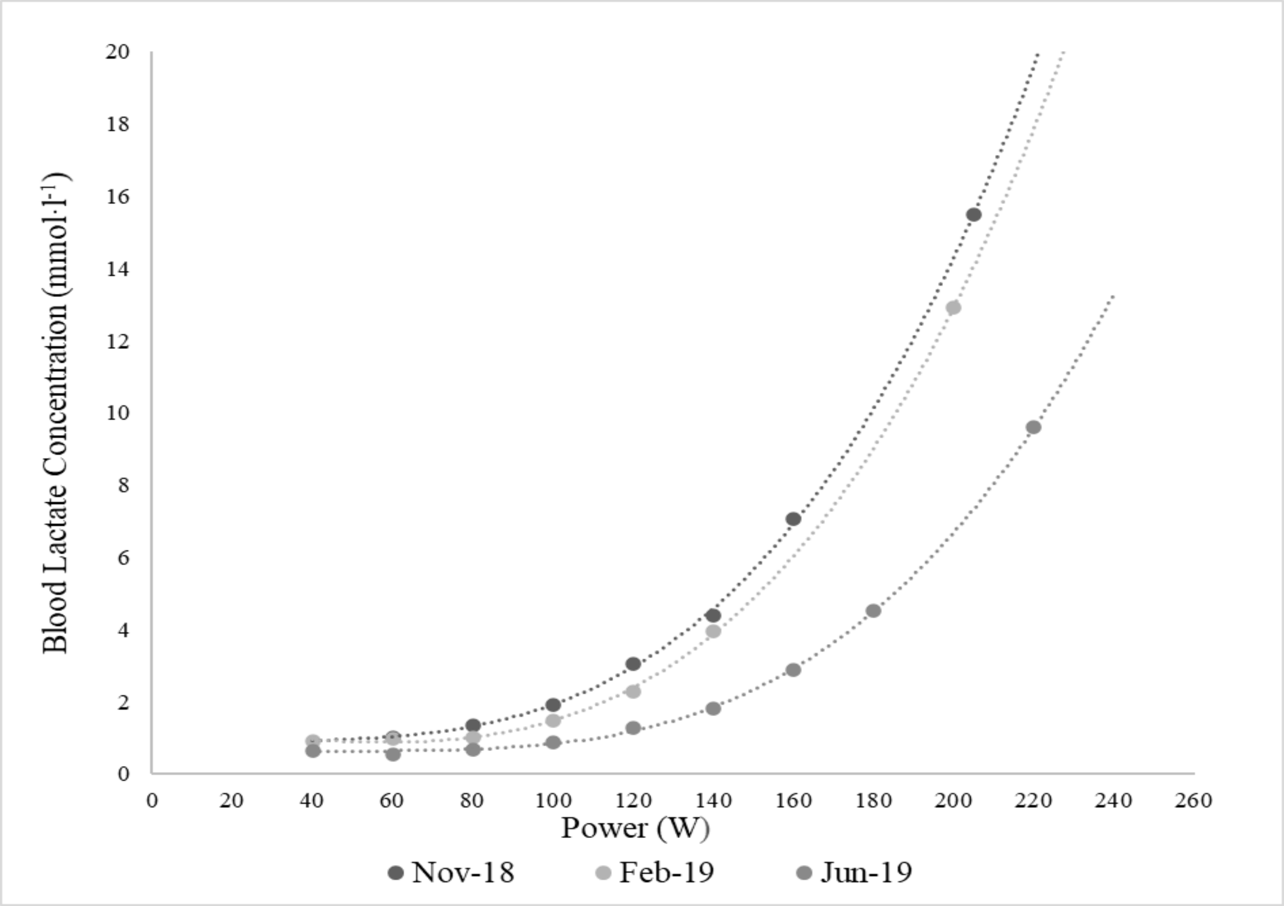

Figure 1. Blood lactate profiles obtained from a graded exercise test performed to volitional exhaustion

Table 3. Net Race Data

Stage	Net Stage Time (hr:mm:ss)	Net Cycling Time (hr:mm:ss)	Distance Covered (km)	Elevation Gain (m)	Average Speed (km·hr^{-1})	Average Cadence (rpm)	Power Output (W)	Heart Rate (b·min^{-1})
1	09:31:18	09:31:18	190.21	1750	20.0	75	96	137
2	08:33:17	18:04:35	177.03	1202	20.7	72	79	121
3	03:13:26	21:18:01	58.10	579	18.0	70	67	111
4	07:56:34	29:14:35	151.42	1211	19.1	73	67	111
5	06:01:18	35:15:53	94.62	1001	15.7	69	59	108
6	01:40:11	36:56:04	31.97	259	19.1	70	66	105
7	01:39:39	38:35:43	34.74	162	20.9	69	57	112
8	09:20:52	47:56:35	154.48	1139	16.5	68	54	100
9	10:13:25	58:10:00	160.85	1421	15.7	66	54	96
10	00:23:04	58:33:04	8.04	57	20.9	67	62	115
11	09:00:56	67:34:00	151.19	1646	16.8	68	67	103
12	07:04:07	74:38:07	148.89	1480	21.1	71	75	111

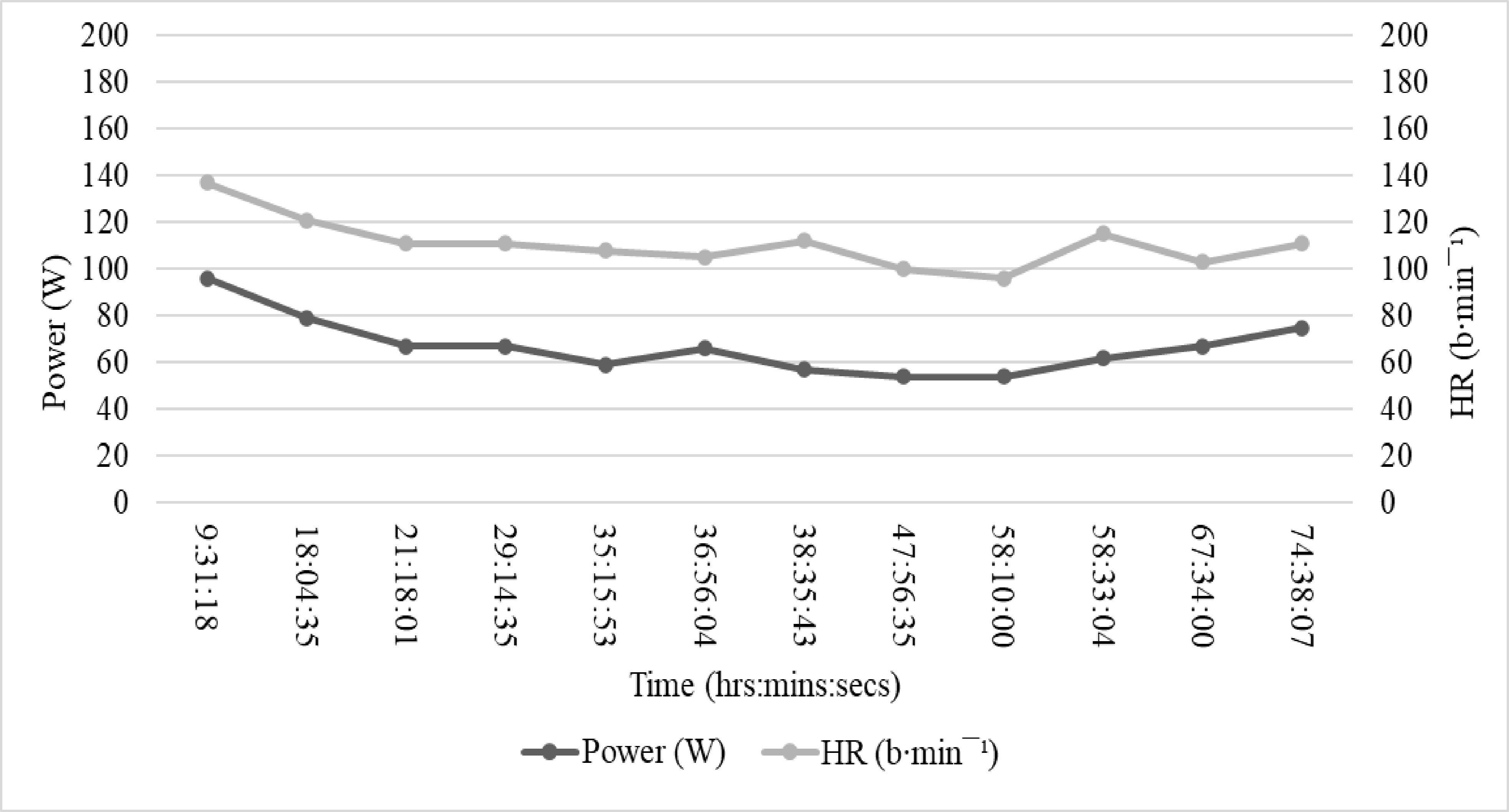

Figure 2. Net cycling time, power output, and heart rate during the JOGLE

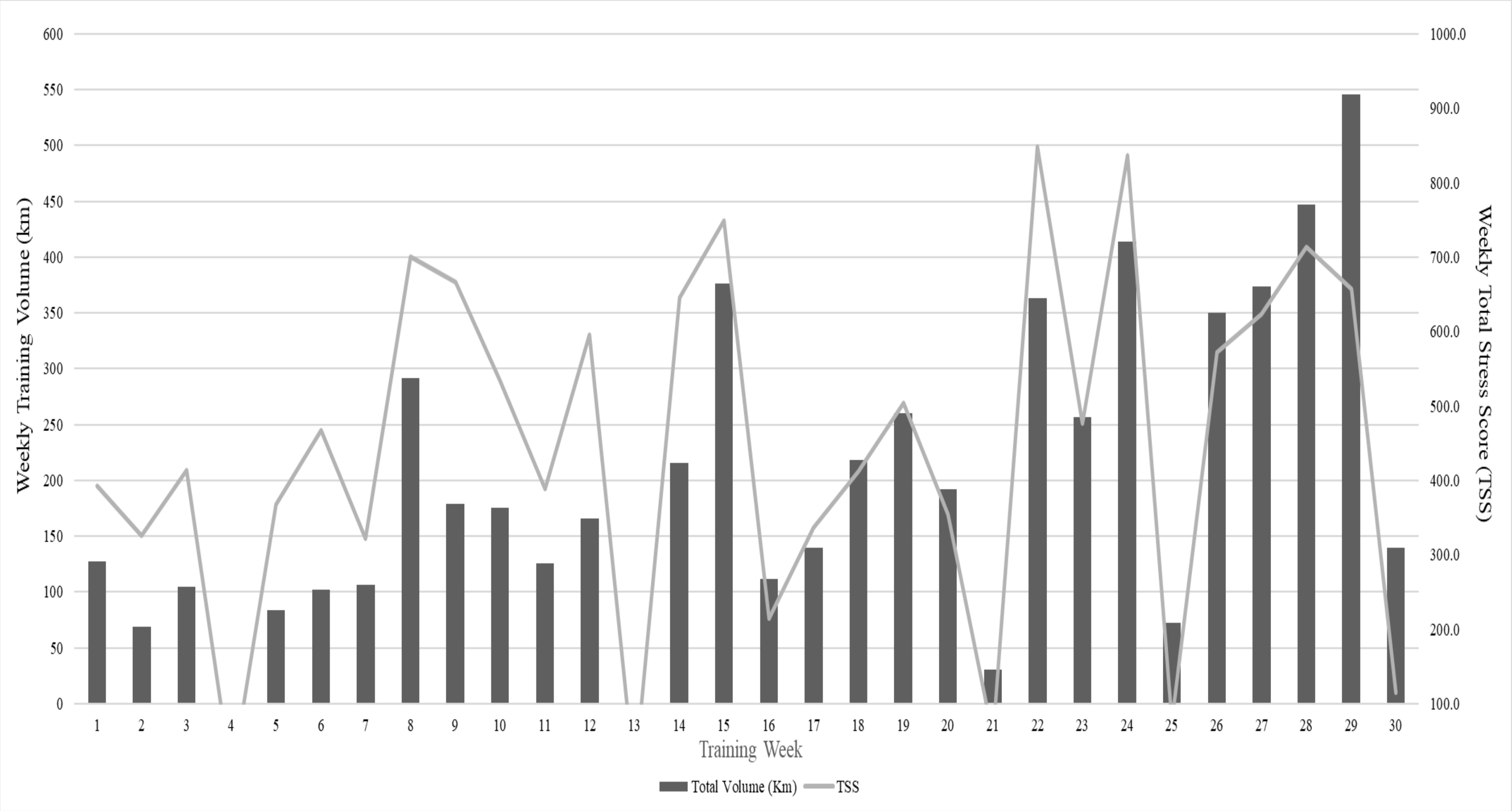

Figure 3. Total cycling training load over the 30-week training protocol.

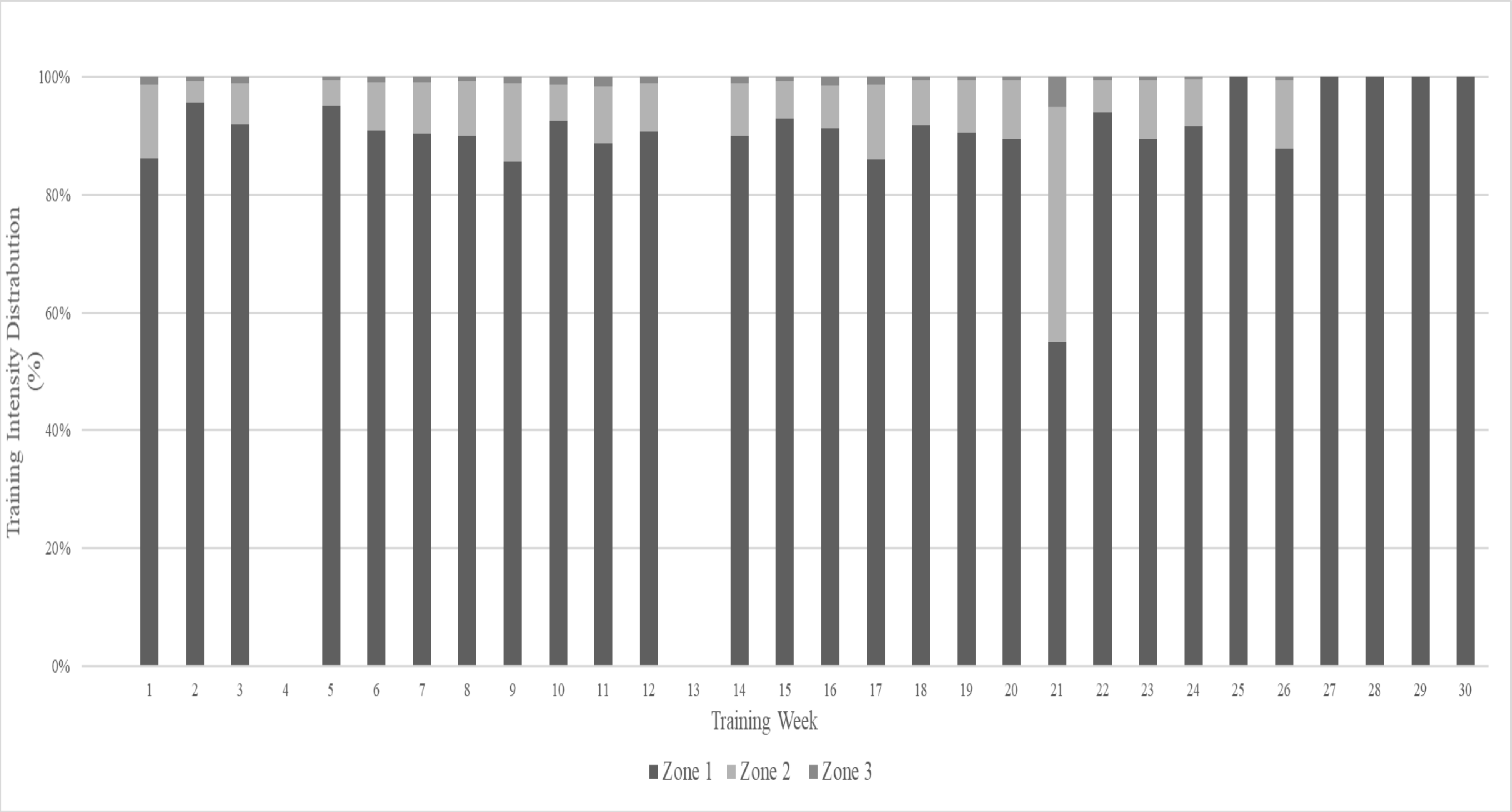

Figure 4. 3-Zone model training intensity distribution