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Human Kinetics
BRIEF REVIEW

Training Characteristics and Competitive Demands in Women Road Cyclists: A Systematic Review

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Purpose: To identify the main training characteristics and competitive demands in women's road cycling. ***Methods:*** A systematic search was conducted on 5 databases according to PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) guidelines. The articles had to be primary studies, written after 1990 with a sample of competitive women between the ages of 15 and 50. The Quality Assessment Tool for Quantitative Studies and the Oxford Levels of Evidence scales were used. ***Results:*** The search yielded 1713 articles, of which 20 were included. Studies on training and competitive demands (n = 5) found that both external and internal loads are higher in women than in men. Studies on strength and endurance training (n = 5) showed that both velocity-based and heavy-load strength training programs performed at least 2 days per week and including 3 to 4 lower-body exercises improved performance. Altitude-training studies (n = 3) found that "Live High–Train Low" was effective to increase performance during the first 9 days after the training camp. The 7 remaining studies focused on a range of topics. The methodological quality was strong for 12 studies and moderate for 8. In contrast, the level of evidence was high in 7 and low in the other 13. ***Conclusions:*** Endurance training and competitive demands in women's road cycling are higher than those of men. Strength training is effective in women when the frequency, intensity, and number of exercises are appropriate, while altitude training should be completed a few days before competing. Further studies are warranted to better define the participants' competitive level, using a methodological design with a higher level of evidence.

Keywords*:* road cycling, female, strength training, altitude training, endurance training

Women's road cycling has grown considerably in popularity in the last couple of years, becoming one of the most important emerging areas of sports for women; this is supported by the increase in the number of participants, professional teams, and annual days of competition.[1] The number of professional UCI (*Union Cycliste Internationale*) Women's World Tour teams and cyclists has doubled from 8 teams and 106 cyclists in 2020 to 14 teams and 191 cyclists in 2022,[2] and it is becoming more common for elite cycling teams to have similar material and facilities for both men's and women's squads. Furthermore, since the introduction of the Women's World Tour in 2016, the number of women's road races has increased from 17 to 23, with events held in 10 different countries.[3] This figure is fast approaching that of competitive men cyclists, whose number of pro-tour teams in 2022 was 18, while the number of World Tour races stood at 32.[4]

Despite this global trend toward sex equality, it has been stated that the number of scientific studies on women's cycling is still low compared with the extensive and diverse research available on men's cycling.[5] However, this trend has changed in the last few years, as a growing number of papers have been published on women's cycling.[6–15] Several studies analyzed training[7] and competition demands[6,8] reporting data on elite cyclists' internal and external loads, such as distance, duration, power output, heart rate, or work. In addition to this, some other studies have focused on women cyclists' adaptation to altitude[16,17] and strength training,[9,18] among other topics, revealing that women cyclists improved their performance by following the "Live High–Train Low" training method, with an increase in both hemoglobin and VO_2max levels.

Therefore, the main purpose of this study was to conduct a systematic review of the training characteristics and competitive demands in women's road cycling. This information would be useful to adapt women cyclists' trainings to their competitive demands, as well as to establish the basis for future studies in this field.

Methods

Information Sources and Search Strategy

This systematic review was conducted following the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis statement[19] from inception to December 2021, by searches in the following electronic databases: MEDLINE, PubMed, Scopus, SPORTDiscus, and Google Scholar, and it was updated in October 2022. The following keywords and filters were used as search criteria for each database consulted (Table 1).

Eligibility Criteria

The inclusion criteria were that studies should be primary sources (ie, longitudinal and cross-sectional studies) published after January 1, 1990 (as it was in this decade when flat pedals were replaced by clipless pedals), in any language that could be translated into English, and with full-text availability. The participants in the study should be competitive women cyclists of any performance level (PL; ie, regional, national, or international road races), between the ages of 15 and 50 (to avoid prepuberty and postmenopausal effects).

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Table 1 Databases Consulted, Search Terms, and Filters Used in the Present Study

Database	Search terms	Filters
PubMed	((((((((woman[Title/Abstract]) OR (women[Title/Abstract])) OR (female[Title/Abstract])) OR (women's'[Title/Abstract])) AND (BICYCLE[Title/Abstract])) OR (BIKE[Title/Abstract])) OR (CYCLISTS[Title/Abstract])) OR (CYCLISTS'[Title/Abstract])) OR (CYCLIST[Title/Abstract])) AND (PERFORMANCE[Title/Abstract])	Female
Scopus	((TITLE-ABS-KEY (woman OR women OR female OR women's) AND TITLE-ABS-KEY (bicycle OR bike OR cyclists OR cyclists' OR cyclist) AND TITLE-ABS-KEY (performance))) AND TITLE-ABS-KEY (female AND cyclists)	—
SPORTDiscus	Woman OR women OR female OR women's (RESUMEN) AND bicycle OR bike OR cyclists OR cyclists' OR cyclist (RESUMEN) AND Performance (RESUMEN)	Academic journal
MEDLINE	Woman OR women OR female OR women's (RESUMEN) AND bicycle OR bike OR cyclists OR cyclists' OR cyclist (RESUMEN) AND Performance (RESUMEN)	Academic journal
Google Scholar	Allintitle: performance AND bicycle OR bike OR cyclists OR cyclists' OR cyclist AND women OR female OR women's OR woman	—

Studies were excluded when men and women's cyclist data were combined in the results (ie, results could not be compared by sex) and when they were not road cyclists (ie, mountain bike, track cycling, BMX). Also, articles focused on commuter cycling, cycling not related to sport, or unrelated to training and competition were excluded.

Study Selection Process and Data Extraction

The selection process was divided into 4 different steps. First, all records retrieved from the databases were exported to Endnote web, where duplicates were automatically removed. The next step consisted of merging all the records into one database. Afterward,, titles and abstracts were assessed against the inclusion criteria by 2 co-authors. Finally, full-text screening was performed in the remaining records by the same co-authors. During all steps, when consensus between both reviewers could not be reached, a third reviewer made the final decision. Reference lists of all included studies were reviewed to determine that no studies were left out.

Data from included studies were collected by the first author in a specific Microsoft Word document created for the occasion. The following characteristics were extracted: author and year of publication, participants' characteristics (ie, number, sex, age, weight, height, VO_2max, P_{max}, and years of cycling experience), study design, results, and conclusions.

Study Risk-of-Bias Assessment

The Quality Assessment Tool for Quantitative Studies[20] was used by 2 researchers to assess the methodological quality of the included studies. This tool has been previously used in systematic reviews on this topic.[21] The assessment tool consists of 6 components: (1) selection bias, (2) study design, (3) confounders, (4) blinding, (5) data collection methods, and (6) withdrawals. All components were rated on a scale of 1 to 3, according to different questions related to each section. The Quality Assessment Tool dictionary was used to determine each score. Due to the heterogeneity of the included studies (please see the next section), component 1 was considered unsuitable for developmental and observational studies, and component 4 for experimental, developmental, and observational studies. Once all components were rated, the methodology of the studies was classified as strong, moderate, or weak according to a global rating. Studies were classified as strong when there were no weak component ratings, moderate when there was at least one weak rating, and weak when there were 2 or more weak ratings.[20]

Synthesis Methods and Reporting Bias Assessment

The included studies were classified according to the PL of the participants as well as their study design to determine potential effect modifiers or heterogeneity. To classify the PL of the participants, the guidelines for classifying female subject groups in cycling research were used.[22] These guidelines establish a scale of PL from 1 to 5 (ie, untrained, active, trained, well-trained, and professional), according to some physiological parameters of the cyclists (ie, absolute and relative VO_2max and peak power output and training status). VO_2max was established as the principal parameter to classify the participants. When relative VO_2max data were not available, relative peak power output was considered (highest fully completed stage during an incremental maximal test). Therefore, cyclists were classified according to their relative VO_2max or peak power output as untrained (PL1, <37 $mL·kg^{-1}·min^{-1}$ or <3.0 $W·kg^{-1}$, respectively); active (PL2, 37–48 $mL·kg^{-1}·min^{-1}$ or 3.0–3.8 $W·kg^{-1}$, respectively); trained (PL3, 48–52 $mL·kg^{-1}·min^{-1}$ or 3.8–4.3 $W·kg^{-1}$, respectively); well-trained (PL4, 52–58 $mL·kg^{-1}·min^{-1}$ or 4.3–5.0 $W·kg^{-1}$, respectively); and professional (PL5, >58 $mL·kg^{-1}·min^{-1}$ or >5.0 $W·kg^{-1}$, respectively). According to the eligibility criteria, untrained cyclists (PL1) were not considered for this review. When participants' data were not available (ie, missing, or unreported participants' data), an email was sent to the authors explaining the main objectives of this review and requesting them to send the missing information within a month.

To identify the study design, the classification proposed by O'Donoghue[23] was implemented. Studies were classified as observational; experimental (pretest posttest randomized-groups design, preexperimental, ex post facto, pretest posttest groups design, or crossover); developmental (longitudinal prospective, longitudinal retrospective, or cross-sectional); survey; or action-research. Historical or case studies were not considered because studies using these methodologies were excluded from the review.

Certainty Assessment

The 2011 Oxford Center for Evidence-Based Medicine Levels of Evidence scale[24] was used to determine the level of evidence of the included studies. Two co-authors classified the studies from level 2 (highest level of evidence) to level 5 (lowest level of evidence). Level 1 was not applied because systematic reviews were not included in this study. Briefly, level was graded down considering study quality, imprecision, indirectness, or because the absolute effect size is very small and graded up if there was a large or large effect size. When agreement could not be reached, a third researcher took the final decision.

Results

Study Selection

Figure 1 shows that a total of 1713 studies were retrieved. After duplicates were removed, 1148 abstracts remained, of which 277 were considered for full-text assessment after abstract and title screening. During full-text assessment, 257 records were excluded as they did not meet the eligibility criteria. Finally, after full-text screening, 20 articles were included in the systematic review.

Study Characteristics

The included studies were published between 1993 and 2022 (Tables 2–5). The mean sample size was 13 (7) participants (range of 5–31 participants) with an age of 26.5 (0.7) years (range of 19.9–47.0 y), a body mass of 58.4 (1.6) kg (range of 53.6–67.4 kg), and a height of 167.7 (5.8) cm (range of 163–171 cm). Most of the studies included professional (40%) and well-trained cyclists (15%), with trained and active cyclists representing 10% and 5% of the total, respectively. However, 30% of the participants could not be classified, as there were no VO_2max or peak power output data available. VO_2max averaged 57.9 (2.4) mL·kg^{-1}·min^{-1} (range of 38.0–65.7 mL·kg^{-1}·min^{-1}), and only 3 studies showed the peak power output (range of 249.0–295.5 W or 4.6–5.3 W·kg^{-1}). Most of the studies were experimental (n = 11, mainly crossover and pretest/posttest randomized-group designs), followed by developmental (n = 5, mainly longitudinal prospective designs) and observational studies (n = 4).

Risk of Bias in Studies and Certainty of Evidence

Table 6 shows that 12 studies reported a strong global rating of quality, while 8 of them reported a moderate rating (no study reported low rating). All studies were checked for potential confounders, and all but 4 used valid and reliable data collection methods. However, the selection bias criteria were not applied in 11 studies, and the scores were between moderate and weak in the

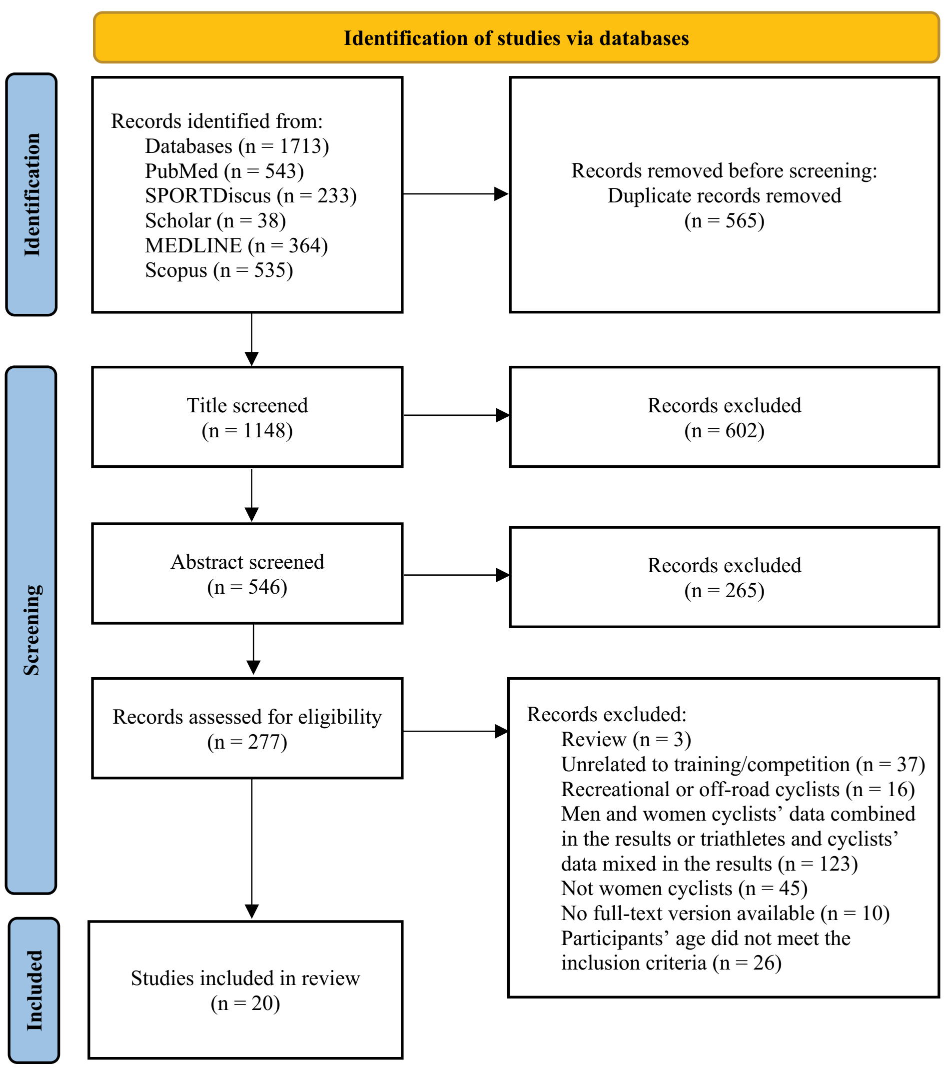

Figure 1 — PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) flow diagram showing the selection process followed.[19]

Table 2 Characteristics and Relevant Outcomes of the Studies on Training Characteristics and Competitive Demands

Study	Number and characteristics of the participants	PL	Study design	Main results and conclusions
Menaspa et al[8]	7 women (age = 28.5 [2.9] y, weight = 55.7 [3.9] kg, height = 165.0 [4.0] cm)	PL5 cyclists (P_{max} 5.3 W·kg^{-1})	Observational	The power data of women cyclists who participated in World Cup races during the 2012–2015 seasons were classified as T10 or N-T10 depending on the race results. Mean maximal power was higher in T10 than in N-T10, with a large effect size for durations between 10 s and 5 min. T10 spent more time at higher intensities (6.75–7.50 W·kg^{-1} and >7.50 W·kg^{-1} powerbands), whereas N-T10 spent more time at a moderate intensity (3.01–3.75 W·kg^{-1}). T10 rode a significantly higher number of short high-intensity efforts (≥10 s, >7.5 W·kg^{-1}) than N-T10 (46 and 30 efforts, respectively).
Sanders et al[6]	30 participants (10 women cyclists age = 24.5 [4.5] y, weight = 60.5 [4.3] kg, height = 169.6 [6.7] cm)	Data not available	Developmental (longitudinal prospective)	Women's World Tour Road cycling races have different demands than men races. Women cyclists spend more time at high-intensity heart rate zones (42% vs 24% in zone 4, and 24% vs 6% in zone 5, respectively) and have a higher relative load (6.02 vs 4.08 TRIMP·km^{-1}). However, men's races have a higher distance (116 vs 183 km, respectively), duration (194 vs 285 min, respectively), power output (167 vs 216 W, respectively), total work (1958 vs 3734 kJ, respectively), and absolute load (TRIMP 700 vs 739 AU, respectively). Coaches and cyclists should consider these differences to plan both trainings sessions and competitions.
Van Erp et al[7]	30 participants (10 women cyclists age = 24.5 [4.5] y, weight = 60.5 [4.3] kg)	Data not available	Developmental (longitudinal retrospective)	Women road cyclists have different training characteristics than men cyclists. Men's trainings have higher distance (91.9 vs 64.1 km, respectively), duration (182 vs 145 min), mean power output (191 vs 138 W, respectively), relative power output (2.6 vs 2.3 W·kg^{-1}), and total work (2151 vs 1223 kJ). However, women cyclists have higher values of %HR_{max} (69.8% vs 65.5%, respectively), relative load per kilometers (TRIMP 4.58 vs 5.72; training stress score 1.23 vs 1.56, respectively), and spend ~13% more time in high-intensity heart rate and power output zones (HR_{max} >80% and ≥91% functional threshold power).
Van Erp and Lamberts[14]	14 women (age = 23.8 [4.4] y, weight = 57.3 [5.6] kg, height = 166 [6.0] cm)	Data not available	Observational	Professional women's cycling races were analyzed and compared according to UCI level (WWT Level 1, or Level 2) and race duration (single day or multiday). Only minor differences were found between race levels in volume (ie, higher duration and distance for WWT) and intensity (ie, higher %HR_{max}, average and relative power output for level 2, and higher Rating of Perceived Exertion for WWT), as opposed to what happens in men's cycling. Moderate differences were found for total elevation gain (ie, higher for WWT) and power output and heart rate intensity zones (ie, more time in higher intensity zones for level 1 races than WWT). When classified by race days, single-day races had higher volume (ie, more duration and distance), load (ie, more total work, TRIMP and training stress score), intensity (ie, higher %HR_{max}, average and relative power output, and Rating of Perceived Exertion), and high-intensity workout (ie, more time in high-intensity power output and heart rate zones) than multiday races, which is similar to what has been reported for men's cycling.
Van Erp and Lamberts[15]	14 women (age = 24.0 [4.0] y)	Data not available	Observational	Professional WWT cyclists were classified as TOP5 or NOT-TOP5 based on their final position on the race (ie, first to fifth vs other position, respectively). TOP5 cyclists produced a higher number of short-duration efforts (≤5 min mean maximal power) and spent more time in the <0.75 W·kg^{-1} powerband and less time in the >3.00 to <3.75 W·kg^{-1} and >3.75 to <4.50 W·kg^{-1} powerbands than NOT-TOP5 cyclists.

Abbreviations: HR_{max}, maximum heart rate; N-T10, non-Top 10; PL, performance level; T10, Top 10; TRIMP, training impulse; UCI, Union Cycliste Internationale; WWT, Women's World Tour.

Table 3 Characteristics of the Strength- and Endurance-Training Studies and Relevant Outcomes

Study	Number and characteristics of the participants	PL	Study design	Main results and conclusions
Bishop et al[25]	21 women (age = 18–42 y, weight = 59.3 [1.7] kg)	PL3 cyclists (VO_2max 48.2 mL·kg^{-1}·min^{-1}, cycling experience 2.5 y)	Experimental (pretest/posttest randomized-groups design)	12 wk of low-volume resistance training of the lower limbs (2 d·wk^{-1}, 3–5 sets [2–8 RM] of parallel squats), designed to increase leg strength, did not improve endurance performance (ie, 1-h cycling test) in women cyclists.
Buono et al[26]	10 women (age = 47.0 [2.0] y, weight = 59.8 [3.0] kg, height = 170.0 [4.0] cm)	5 PL3 cyclists (VO_2max 51 mL·kg^{-1}·min^{-1})	Developmental (longitudinal prospective)	Elite master women cyclists increased their VO_2max by 8% (from 51 to 55 mL·kg^{-1}·min^{-1}), blood lactate threshold by 23% (from 150 to 185 W), and improved their performance on a flat 13.5-km TT by 8% (from 1824 to 1788 s) following 6 mo of high-intensity training (4.7 sessions/wk for ~225 km, and 1-h high-intensity interval training session at heart rate > 160 beats·min^{-1}).
Montalvo-Pérez et al[9]	17 women (age = 26.0 [7.0] y, weight = 58.0 [6] kg, height = 166.9 [6.0] cm)	PL4 cyclists (VO_2max 55 mL·kg^{-1}·min^{-1})	Experimental (pretest posttest- randomized-groups design)	A 6-wk velocity-based resistance training (2 d·wk^{-1}, 3 sets, maximum number of repetitions at >90% of optimum power load of squats, hip thrusts, and split squats), resulted in more muscle strength and power on hip thrust exercise in women cyclists than a traditional resistance training (2 d·wk^{-1}, 3 sets, 5–8 repetitions at 80%–90% RM of squats, hip thrusts, and split squats). In addition, velocity-based resistance training significantly improved endurance performance (higher average power output and power output relative to lower-body muscle mass) on an 8-min cycling TT.
San Emeterio et al[12]	31 women (age = 19.8 [5.3] y, weight = 53.6 [2.8] kg, height = 164.8 [3.4] cm)	Data not available	Experimental (crossover)	High-intensity training (7 × 6-min ramped intervals) influenced lumbopelvic complex stability (single-leg-deadlift and bird-modified dog tests assessed via OCTOcore app) in women cyclists. Both tests improved by 15% and 17%, respectively, after training, so it seems that there is a relation between core stability and lower- and upper-limb mechanics during cycling. Also, OCTOcore app showed high reproducibility (ICC = .83), so it is a reliable tool that cyclists could use to monitor these lumbopelvic stability changes during their trainings.
Vikmoen et al[18]	19 women (age = 33.2 [7.8] y, weight = 64.0 [6.7] kg, height = 169.5 [4.0] cm)	PL4 cyclists (VO_2max 54.1 mL·kg^{-1}·min^{-1})	Experimental (pretest posttest randomized-groups design)	11 wk of heavy strength training (2 d·wk^{-1}, 3 sets, 4–10 RM of half squat, one-legged leg press, standing one-legged hip flexion, and ankle plantar flexion) has a positive effect on women cyclists' performance. Participants significantly improved mean power output (6.4%), fractional utilization of VO_2max (3.3%), and cycling economy on a 40-min all-out test, as well as 1RM in one-legged leg press (38.6%). Quadriceps muscle cross-sectional area (7.4%) and the proportion of type IIA fibers in vastus lateralis (12%) were also increased, while the proportion of type IIAX-IIX muscle fibers decreased (–9%). Therefore, women cyclists should include heavy strength training in their training routines.

Abbreviations: ICC, intraclass correlation coefficient; PL, performance level; RM, repetition maximum; TT, time trial; VO_2max, maximal oxygen uptake.

Table 4 Characteristics of the Altitude-Training Studies and Relevant Outcomes

Study	Number and characteristics of the participants	PL	Study design	Main results and conclusions
Garvican et al[16]	11 women (age = 21.4 [3.9] y, weight = 58.9 [6.0] kg, height = 169.3 [4.6] cm)	PL5 cyclists (VO_2max 61.6 mL·kg^{-1}·min^{-1}, P_{max} 295.5 W or 5.0 W·kg^{-1})	Experimental (ex post facto)	Women cyclists were exposed to simulated normobaric hypoxia LHTL (16 h·d^{-1}, 3000 m) for 26 continuous days. There was a 4% improvement in a maximal 4-min cycling performance despite deliberately blocking the increases in hemoglobin mass (via repeated phlebotomy), which implies that accelerated erythropoiesis is not the sole mechanism by which LHTL improves performance.
Hahn et al[27]	Study 1: 17 participants (8 women cyclists age = 21.0 [1.2] y, weight = 58.8 [1.3] kg, height = 167.1 [1.5] cm) Study 2: 45 participants (12 women cyclists age = 25.5 [1.3] y, weight = 59.8 [1.1] kg, height = 169.2 [1.5] cm)	Study 1: PL5 cyclists (VO_2max 61.1 mL·kg^{-1}·min^{-1}) Study 2: PL5 cyclists (VO_2max 63.0 mL·kg^{-1}·min^{-1})	Study 1: Experimental (crossover) Study 2: Experimental (pretest posttest groups design)	The first study shows that normobaric hypoxia compromises training intensity in women cyclists, as they selected lower workloads during 2 high-intensity interval trainings in hypoxia (2100 m) than in normoxia (ie, 226 vs 244 W during 3 × 10-min efforts at the highest possible average power output, and 459 vs 477 W during 3 sets of 6 × 15-s sprints). In the second study, women cyclists slept 12 nights in moderately hypoxic conditions (simulated altitude of 2650 m). Although it did not increase hemoglobin mass or VO_2max, it was associated with a performance improvement of 2.3% for a 4-min ergometer supramaximal effort.
Pottgiesser et al[17]	5 women (age = 20.1 [2.1] y, weight = 61.3 [4.6] kg, height = 171.0 [4.0] cm)	PL5 cyclists (VO_2max 61.5 mL·kg^{-1}·min^{-1})	Experimental (crossover)	Women cyclists attended an LHTL training camp where they were exposed to simulated normobaric altitude (16 h·d^{-1}, 3000 m) for 26 nights and trained at ~600 m above sea level. Although LHTL increased hemoglobin mass by 5.5%, 9 d after the return to normoxic conditions, it decreased by 3%. This may be an indicator that the interval between the LHTL training camp and the competition should be kept to a minimum, as benefits of LHTL on hemoglobin mass can be quickly lost.

Abbreviations: LHTL, Live High–Train Low; PL, performance level; VO_2max, maximal oxygen uptake.

other 9. Withdrawals were described in 17 studies, the study design was moderate in another 17 studies, and blinding criteria were deemed not applicable for all studies. On the other hand, 7 studies were rated as Level 2 on the Oxford Levels of Evidence, 8 as Level 3, and 5 as Level 4.

Results and Synthesis of Individual Studies

Training Characteristics and Competitive Demands

Five studies focused on this topic, showing that women cyclists' training and competitions had less absolute and relative power output, and total and relative work when compared with men (Table 2). However, women cyclists spent more time at high-intensity heart rate zones than men and pedaled at a higher relative power output.[6,7] When comparing women cyclists of different competitive levels, Top 10 and Top 5 World Cup cyclists had higher mean maximal power output, spent more time at higher intensities, and performed a significantly higher number of short high-intensity efforts than the rest of the participants.[8,15] Single-day races also had higher volume, load, and intensity than multiday races.[14] However, when women's cycling races were classified by UCI level, minor differences were found in-between in volume and relative intensity.[14]

Strength and Endurance Training

Five other studies focused on this topic, although they analyzed different types of training (Table 3). Six-week velocity-based resistance training,[9] and 11 weeks of heavy strength training[18] had a positive effect on cycling performance-related variables. In contrast, 12 weeks of low-volume resistance training of the lower limbs did not improve endurance cycling performance.[25] San Emeterio et al[12] found a relationship between core stability and lower- and upper-limb mechanics during cycling, as high-intensity cycling training had an effect on lumbopelvic complex stability. Furthermore, Buono et al[26] demonstrated that women cyclists improved their performance after 6 months of high-intensity endurance training.

Altitude Training

Three studies focused on altitude training and its relationship to performance-related variables (Table 4). Garvican et al[16] reported that the "Live High–Train Low" training method improved cycling performance through hematological (ie, accelerated erythropoiesis) and nonhematological mechanisms. Hahn et al[27] also found that this training method improved cycling performance (ie, 2.3% performance improvement for a 4-min ergometer supramaximal

Table 5 Characteristics and Relevant Outcomes of the Studies Classified as "Other Topics"

Study	Number and characteristics of the participants	PL	Study design	Main results and conclusions
Barreto et al[10]	5 women (age = 26.0 [4.0] y, weight = 53.6 [4.2] kg, height = 164.0 [5.0] cm)	PL4 cyclists (VO_2max 55.5 mL·kg^{-1}·min^{-1}, P_{max} 249 W or 4.6 W·kg^{-1}, cycling experience 10 y)	Developmental (longitudinal prospective)	Women cyclists rode a mean of 193 d over the year, covering a mean total distance of 11,124 km. Relative VO_2max decreased over the season, but not anaerobic power (30-s Wingate test and 4-km time-trial performance), which remained unchanged. The percentage of riding days spent in optimal estimated energy availability (ie, amount of energy available for basic physiological processes) was generally low, with the total caloric consumption on cycling days been lower than the one prescribed for most of the cyclists.
Chaffin et al[28]	12 participants (5 women: age = 30.4 [7.2] y, weight = 67.4 [7.3] kg, height = 163.0 [5.0] cm)	PL2 cyclists (VO_2max 38 mL·kg^{-1}·min^{-1})	Experimental (preexperimental)	Competitive cyclists performed a 30-min self-paced maximal test, which was divided into 3 periods (1–10, 10–20, and 20–30 min). Overall, an even pace strategy was observed in both men and women cyclists, as no significant differences were found in power output (mean 229, 223, and 233 W, respectively), VO_2max, heart rate, or blood lactate concentration across the 3 periods. Therefore, even pacing seems to be the optimal strategy for 30-min cycling TTs.
Decroix et al[29]	12 women (age = 24.6 [4.4] y, weight = 57.7 [5.2] kg, height = 170.0 [7.0] cm)	PL5 cyclists (VO_2max 59.4 mL·kg^{-1}·min^{-1})	Experimental (ex post facto)	After 8 d of a training camp, women cyclists were classified as OR or Positive AD based on their changes in performance on a 30-min TT from day 1 to day 8. Significant differences were found in power output (OR: 92.97%, AD: 101.72%), maximal hear rate (OR: 97.20%, AD: 101.05%), and reaction time on a cognitive test (OR: +3.35%, AD: –4.59%). Therefore, both the physical and cognitive tests could be useful to monitor training adaptations in women cyclists.
Garvican et al[31]	10 women (age = 23.9 [4.5] y, weight = 57.5 [5.3] kg, height = 170.9 [5.0] cm)	PL5 cyclists (VO_2max 63.3 mL·kg^{-1}·min^{-1})	Developmental (longitudinal prospective)	Women cyclists had a 3% variation in hemoglobin mass during a competitive season, which could partially be explained by the changes in the training load (increasing training load by 10% resulted in a 1% increase of hemoglobin mass). Hemoglobin mass and maximal mean power were also related (1% change in hemoglobin mass was associated with a 1% change in maximal 4-min mean power during training or competition). Thus, changes in hemoglobin mass should be considered when analyzing changes in performance.
Nelson et al[11]	6 women (age = 36.6 [4.0] y, weight = 65.0 [4.7] kg)	Data not available	Experimental (crossover)	The rHRI method was used to assess the effect of training (light, heavy, and tapering) on women cyclists' performance (5- and 60-min TTs). Positive correlations were found between rHRI and both 5- (r = .65) and 50-min (r = .70) TTs. Therefore, rHRI is a useful method for predicting fatigue/recovery status on women cyclists.
Pfeiffer et al[30]	13 women (age = 28.0 [2.8] y, weight = 61.1 [3.7] kg, height = 168.7 [5.0] cm)	PL5 cyclists (VO_2max 64.2 mL·kg^{-1}·min^{-1}more than a year of cycling experience)	Experimental (preexperimental)	Several indices of aerobic capacity (absolute and relative VO_2max, V_e, V_e/VO_2max, and HR/VO_2max) were recorded in order to analyze their relationship to women cyclists' performance in a multistage race (16 consecutive stages). Relative VO_2max (mean 64.2 mL·kg^{-1}·min^{-1}) was significantly correlated with the total time of 12 stages, while HR/VO_2max was correlated with the total time of 4 stages, 3 of which were TTs. Therefore, relative VO_2max seems to account for ~80% of women cyclist's performance in multistage events.
Valenzuela et al[13]	48 participants (26 women cyclists age = 27.0 [5.0] y, weight = 54.4 [6.6] kg, height = 167 [6.0] cm)	PL5 cyclists (VO_2max 65.7 mL·kg^{-1}·min^{-1})	Observational	Training and competition power profiles from professional men and women cyclists were analyzed to determine the effect of ambient temperature on performance. The results suggest that 10–25 °C is the optimal range of temperature for women cyclists, as they attained the highest mean maximal power values at this range and their lowest values when temperature was lower than 5 °C and higher than 35 °C. Therefore, it follows a reverse U-shaped relationship, similar to what happens in men cycling.

Abbreviations: AD, adapted; HR, heart rate; PL, performance level; OR, overreached; rHRI, maximal rate of heart rate; TT, time trial; VO_2max, maximal oxygen uptake.

Table 6 Results of the Quality Assessment Scores (Global Rating) and Oxford LoE From the Included Studies

Study	Selection bias	Study design	Confounders	Blinding	Data	Withdrawal	Global rating	LoE
Barreto et al[10]	3	2	1	—	1	1	Moderate	3
Bishop et al[25]	—	1	1	—	1	1	Strong	2
Buono et al[26]	2	2	1	—	1	1	Strong	3
Chaffin et al[28]	—	2	1	—	1	1	Strong	4
Decroix et al[29]	—	2	1	—	1	2	Strong	4
Garvican et al[31]	2	2	1	—	1	1	Strong	3
Garvican et al[16]	—	2	1	—	1	2	Strong	4
Hahn et al[27]	—	2	1	—	1	1	Strong	3
Menaspa et al[8]	3	2	1	—	1	1	Moderate	2
Montalvo et al[9]	—	1	1	—	1	1	Strong	2
Nelson et al[11]	—	2	1	—	1	1	Strong	3
Pfeiffer et al[30]	—	2	1	—	1	1	Strong	4
Pottgiesser et al[17]	—	2	1	—	1	1	Strong	3
Sanders et al[6]	3	2	1	—	1	1	Moderate	3
San Emeterio et al[12]	—	2	1	—	3	1	Moderate	4
Valenzuela et al[13]	3	2	1	—	2	1	Moderate	2
Van Erp et al[7]	3	2	1	—	1	1	Moderate	3
Van Erp and Lamberts[14]	3	2	1	—	2	1	Moderate	2
Van Erp and Lamberts[15]	3	2	1	—	2	1	Moderate	2
Vikmoen et al[18]	—	1	1	—	1	2	Strong	2

Note: "Data" is data-collecting methods. The quality assessment scores criteria were 1, strong; 2, moderate; 3, weak, and —, not applicable. The LoE was classified from 1, highest level, to 5, lowest level. Please see the "Methods" section for more details about the applied criteria and the assessment of both global rating and LoE. LoE, Oxford Levels of Evidence

effort), and that normobaric hypoxia compromises training intensity in comparison to normoxia. Finally, Pottgiesser et al[17] determined that the interval between a "Live High–Train Low" training camp and competition should be as short as possible, as hemoglobin mass decreased quickly after the return to normoxic conditions.

Other Topics

The remaining 7 studies focused on a wide range of topics, such as optimal pacing for 30-minute time trials, which was reported to be even pacing,[28] or the usefulness of the rHRI method to assess the effect of training in cyclists (Table 5).[11] Decroix et al[29] proved that a physical and a cognitive test were useful to monitor training adaptations, and Pfeiffer et al[30] found relative VO_2max to be significantly correlated with 80% of women cyclists' performance in multiday races. Garvican et al[31] obtained a 3% variation in hemoglobin during a competitive season, which could partly be explained by differences in training load. Valenzuela et al[13] found a reversed U-shaped relationship between performance and ambient temperature, 10 °C to 25 °C being the optimal temperature range for women cyclists' trainings and competitions. Finally, it was also found that women cyclists' relative VO_2max decreases over a competitive season, although anaerobic power does not.[10]

Discussion

This is the first systematic review summarizing the training characteristics and competitive demands in women's road cycling. Several differences were found between men's and women's training and competitions, as women have higher demands than men. It was also found that heavy strength training and velocity-based resistance training have a favorable effect on women cyclists' performance, as long as the frequency, intensity, and number of lower body exercises are appropriate. Furthermore, "Live High–Train Low" training was reported to be effective for women cyclists in the first few days after returning to sea level. It has also been observed that the methodological quality and level of evidence of the studies could be improved by specifying the participants' characteristics (ie, VO_2max, peak power output, or number of withdrawals), and by using study designs with a higher level of evidence.

Currently, there is some agreement regarding the characteristics of women's road cycling competitions. Women cyclists endure a higher internal (ie, physiological variables) and external loads (eg, training impulse [TRIMP], training stress score) than men.[6] This is due to shorter race distances and durations but also to other factors, such as lower aerobic capacity and leg muscle mass.[6] It has also been stated that the women who finished in the Top 10 and Top 5 at World Cup races had a higher number of short-duration efforts and spent more time in high-intensity powerbands than other women cyclists, similar to what has been observed in professional men's cycling.[32] This highlights the importance of fatigue resistance (ie, the ability to maintain high power outputs after workload) in road cycling.[8,15] Another study has focused on the characteristics of women cycling competitions at different UCI levels, finding minor differences in intensity, internal and external loads, and performance.[14] This is in contrast with what has been observed in men and it could be justified by several factors, such as the lower number of professional teams and competition days for women (ie, high-level women have to compete in low-level competitions), as well as a lack of development of the women's under-23 category.[14]

One study has analyzed the internal and external load of cycling training in women,[7] reporting similar characteristics to those of competition (ie, a shorter duration and higher intensity than men's trainings). These authors stated that this similarity could be due not only to an adaptation of training sessions to competition requirements, but also to the need for coaches to schedule training sessions that cyclists can balance with studies or work (ie, most women cyclists are not professionals), as well as to the lower frequency of their racing calendar (ie, almost half the race days than men). Therefore, more studies that assess women cyclists' training characteristics are needed, as the number of professional teams and competition days has increased significantly since the aforementioned study was carried out.[2,3]

Three studies have analyzed the effect of strength training on performance and its related variables in women cyclists,[9,18,25] and all but one[25] indicated that adding strength training to cycling training improves performance. However, in this study,[25] a single strength training exercise (ie, parallel squat) was used (ie, 12 wk, 2 d·wk^{-1}, 3–5 sets of 2–8 RM), while the other studies used 3 to 4 lower body exercises (ie, squats, hip thrusts, one-legged leg press, etc) and similar training frequency (ie, 6–12 wk, 2 d·wk^{-1}, 3 sets of 4–10 RM), which could justify the lack of positive results. The studies that did observe favorable effects of strength training[9,18] have shown that both heavy strength training and velocity-based resistance training have a positive effect on several variables related to the performance of women cyclists. This is in line with what has been reported in a recent review, which stated that these improvements in performance are caused by an increase in both cycling economy and VO_2max.[33] Therefore, it seems that women cyclists benefit from strength training programs (ie, heavy strength training and velocity-based resistance training), as long as they include the appropriate frequency, intensity, and number of lower body exercises.

Another 3 studies have analyzed the effect of altitude training on women cyclists' performance,[16,17,27] all of them suggesting that "Live High–Train Low" is effective for them. It was also detected that the improvements obtained in women cyclists with this kind of training are lost in a short space of time,[17] disappearing almost completely over 9 days after returning to sea level. Therefore, it may be advisable that the interval between this type of training and competition should be as short as possible for women cyclists to compete while the benefits are still evident. However, more studies with control groups are needed[34–36] to determine the effectiveness of this type of training in improving performance in women cyclists, as well as to determine the duration of its potential benefits.

It should be highlighted that few studies (n = 20) addressed the training characteristics and competitive demands in women's road cycling (Table 6). A high level of heterogeneity has been observed in the number (ie, from 5 to 31 cyclists) and characteristics (eg, 19.9–47.0 y of age) of the participants, as well as in the study design (eg, observational, experimental, or developmental). This may be due to the wide variety of objectives and topics found due to emerging interest in this population. Almost a third of the studies (30%) did not report cyclists' VO_2max values and only 3 studies reported peak power output values, despite having requested them from the corresponding authors (please see "Methods" section). Decroix et al[22] stated that these 2 are the most reliable values to determine the PL of cyclists, so future studies should measure VO_2max and peak power output values of the participants to allow their classification. Most studies of the remaining 70% were carried out on professional and well-trained cyclists (55%). Taking Spanish cycling as an example, where only 1.4% of the total of licensed women cyclists (ie, 83 of 5924) compete in UCI World Tour or Continental Teams,[2,37] it is evident that more studies on women cyclists of Performance Levels 2 and 3 are needed (ie, active and trained cyclists, respectively).

Table 6 also shows that the included studies have obtained better ratings in terms of methodological quality (ie, Global rating, 60% are strong and 40% moderate) than at the level of evidence (ie, LoE, 35% Level 2, and 65% Levels 3 and 4). The methodological quality obtained using the Quality Assessment Tool for Quantitative Studies is good, but when the items were not applicable (ie, "blinding criteria" and "selection bias criteria"), they did not score on the scale. This had a positive effect on the global rating, resulting in a high number of studies obtaining the "strong" level. In addition, many studies did not specify participants' withdrawals, resulting in a moderate study design, which negatively affected the level of evidence (ie, LoE is mainly based on the study design). Therefore, future studies on women cyclists should consider the limitations of the scale used to assess the methodological quality of the studies, as well as the difficulties indicated above in order to improve the level of evidence.

Finally, the small number of studies carried out on women cyclists and their heterogeneity explain why 7 of the 20 studies were not analyzed (ie, high variety of the topics), and this has prevented a quantitative analysis of the results (ie, performing a meta-analysis). Future studies should include a higher number of topic-related homogeneous studies considering the recommendations of the present systematic review. Likewise, selecting a methodological quality scale that could be applied to studies with such different methodologies was challenging. The Quality Assessment Tool for Quantitative Studies was chosen because it had already been used in systematic reviews of cycling,[21] and because we understand that the use of several scales depending on the study design (eg, one scale for experimental studies and another for development studies), could bias the results. Future studies should consider the above-mentioned limitations of this scale. However, to the best of our knowledge, this study is the only review carried out on the training characteristics and competitive demands of women road cyclists.

Practical Applications

The results of this systematic review indicate that women's road cyclists spend more time at high-intensity heart rate zones and ride at a higher relative load than men during trainings and competitions. Moreover, it has been observed that Top 5 world cup cyclists are able to perform a greater number of short high-intensity efforts than the rest of the participants during competitions. This information can be helpful for coaches and personal trainers to adapt women cyclists' trainings to their competitive requirements.

Furthermore, it has been observed that strength and altitude training programs have a positive effect on performance-related variables of women road cyclists. They benefit from velocity-based resistance training and heavy strength training programs, performing at least 3 to 4 lower body exercises 2 days per week. When it comes to altitude training, women cyclists are encouraged to go on "Live High–Train Low" training camps to improve their performance. However, they should compete within the first few days to profit from these altitude training benefits.

Finally, this systematic review identifies the methodological weakness of previous studies and establishes future lines of research in women's cycling. Academics conducting research on this topic should take this into consideration when planning the objectives and methodology of their studies.

Conclusions

Women cyclists have higher external (ie, training impulse [TRIMP], training stress score) and internal loads (ie, physiological variables) than men during training and competition, mainly due to their shorter competitive distance (ie, maximum of 160 vs 280 km, respectively) and other factors such as the historically lower number of women's professional teams and competition days. Studies also agree on the benefits of strength (ie, high-intensity training with sufficient number of lower-body exercises) and altitude training (ie, "Live High–Train Low") to performance-related variables, detecting that this last type of training has benefits when the competition is performed in the first few days after returning from the training camp. More studies are needed to confirm the preliminary observations obtained for other topics (eg, optimal time-trial pacing, hemoglobin mass, and VO_2max variation during a season, the effect of ambient temperature on performance). In addition, future studies should describe the characteristics of the participants (ie, VO_2max and peak power output), use a control group (ie, strength and altitude training), and use a study design with a higher level of scientific evidence.

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