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Cycling position optimisation – a systematic review of the impact of positional changes on biomechanical and physiological factors in cycling

Sean Philip Husband [a], Barney Wainwright [b], Fiona Wilson [c], Danielle Crump [d], David Mockler [e], Paul Carragher [f], Frank Nugent [g] and Ciaran Knut Simms [a]

[a]School of Engineering and Centre for Biomedical Engineering, Trinity College Dublin, Dublin, Ireland; [b]Carnegie School of Sport, Leeds Beckett University, Leeds, UK; [c]School of Medicine, Trinity College Dublin, Ireland; [d]School of Health and Social Care, University of Lincoln, Lincoln, UK; [e]Trinity College Dublin, Dublin, Ireland; [f]Department of Physiotherapy, Sport Ireland Institute, Dublin, Ireland; [g]Department of Physical Education & Sport Sciences, University of Limerick, Lmerick, Ireland

ABSTRACT
Bike positional configuration changes strongly affect cycling performance. While consensus has emerged on saddle height optimisation, there is none for the relationship between other bike positional variables and cycling performance. Accordingly, this systematic review examines the effect of all major positional variables on performance in cycling, assessing differences between cycling disciplines and sex where possible. The systematic review, conducted per PRISMA guidelines, searched databases including Embase, Web of Science, Medline, and CINAHL, screening 16,578 studies. Of these, 47 were fully analysed. Study quality assessment using the NIH tool revealed none rated "good", 5 "fair" and 33 "poor". The analysis involved 724 participants (90 female, 454 male, 180 sex unstated). Studies focused on trunk angle/upper body position, handlebar height, Q factor, foot position, saddle fore-aft/height, seat tube angle and crank length. Participant cycling disciplines were often unspecified and few papers address women cyclists specifically. Key findings were associated with changing saddle height, trunk angle and saddle fore-aft. For trunk angle, accounting for the biomechanical and physiological effects as well as aerodynamic changes is important. Saddle fore-aft affects the hip angle and trunk angle. There are no clear recommendations for crank length, handlebar height, Q factor or cleat position.

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KEYWORDS
Bike fitting; position optimisation; saddle height; trunk angle; handlebar height

1. Introduction

RJSP_A_2394752The position that an individual adopts on a bicycle is determined by the requirements of the cycling task (e.g., racing in comparison to commuting), the type of bike (e.g., time trial, dropped handlebar racing bike or an upright Dutch-style commuting bike) and aspects of the individual's anthropometry, anatomy and physiology (Antequera-Vinque et al., 2023; Holliday & Swart, 2021; Malizia & Blocken, 2021). A cyclist's position on the bike greatly affects cycling performance (Malizia & Blocken, 2021; Turpin & Watier, 2020), comfort (Ayachi et al., 2014; Chiu et al., 2013) and injury potential (Balasubramanian et al., 2014; Bini & Priego-Quesada, 2022; Bini et al., 2011). Therefore, generating an understanding of the relationships between different positions on the bike or the effects of changes in configuration have been the subject of many investigations. For the same reasons, establishing an individual's optimal position for performance for the demands of the cycling task (e.g., road racing, time trialling, long-distance challenges) is an objective for cyclists at all ends of the performance spectrum – from professional cyclists to recreational cyclists. For that purpose, "bike fitting" has been described as "one of the primary ways to optimise performance and comfort and to avoid injury", consisting of adjusting the foot-shoe-pedal interface, pelvis-saddle interface, and hand-handlebar interface considering the individual characteristics (Millour et al., 2023).

From a performance perspective, the identification of an "optimal position" can be considered as an individual's bike configuration and posture that permits the maximal sustainable speed for the task in question. However, determining an optimal position through a bike fitting process is particularly challenging. It requires a balance of maximising the speed potential (reducing aerodynamic drag and increasing the sustainable power output) while maintaining sufficient comfort at each contact point and minimising the potential for chronic injury (de Vey Mestdagh, 1998). All of this must occur within the constraints of the rider's flexibility and the bicycle's geometry, adjustability and parts that are available. The skilled practitioner must attempt to utilise the existing scientific knowledge and apply it to the particular circumstances and requirements of the cyclist. This is a process that ideally involves the collection of a combination of complex physiological, biomechanical, anthropometric and aerodynamic data, followed by a series of position and equipment interventions, and further evaluations.

Methods of measuring and defining positional changes in cycling have developed rapidly in the last 5–10 years (Millour

CONTACT Sean Philip Husband husbands@tcd.ie School of Engineering and Centre for Biomedical Engineering, Trinity College Dublin, Ireland
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et al., 2023; Swart & Holliday, 2019). Initially, generic anthropometric-based formulae were used to determine key variables such as saddle height (de Vey Mestdagh, 1998), but the development of accurate and affordable motion capture systems has improved the ability to quantify relevant kinematic measures (Holliday, Fisher, et al., 2019). Recent developments in technology have facilitated the measurement of additional factors that are used by some practitioners to inform their practice: pressure mapping of the saddle quantifies the effects of changes in position and saddle choice (Larsen et al., 2018); inertial measurement units (IMUs – See appendix C for abbreviations) may be used to measure aspects of cycling kinematics in an outdoor environment (Thompson et al., 2024); pedal forces may be recorded to measure pedalling effectiveness (Bini & Hume, 2015) and determine the effects of changes in position on pedal forces (Jongerius et al., 2022); metabolic carts can be used to quantify the energy cost and efficiency of cycling in different positions (Ettema & Lorås, 2009; Peveler, 2008; Peveler & Green, 2011).

Measures of aerodynamic drag are often a key driver behind positional changes for some cycling disciplines and events (e.g., time trial, team and individual pursuit), for which wind tunnel or track testing can be used (Malizia & Blocken, 2021). With the appropriate level of practitioner knowledge and expertise, many of these tools can be utilised to inform the bike fitting process and identify an individual's optimal cycling position. However, these tools are not universally used due to their cost, availability and complexity, while the scientific evidence for their use in decision-making is not always clear (Millour et al., 2023).

Bini and Priego-Quesada (2022) updated a previous narrative review (Bini et al., 2011) with a systematic review of saddle height in relation to measurement methods, performance, and injury. One of the limitations regarding the Bini et al. (2011) review is that participants with low levels of cycling experience were used. Competitive cyclists often have highly specialised physiological and biomechanical adaptations that influence how positional changes affect their performance (Hopker et al., 2017). Additionally, recreational cyclists may not be as familiar with or as adept at maintaining optimal cycling positions (Cain et al., 2016), which can affect their ability to sustain certain positions. As the focus of the current review is on positional factors related to performance, we acknowledge that there is some common content with the R. Bini, Hume, and Kilding (2014) review. However, their review focusses only on saddle height, whereas this review explores the inter-relationship between saddle height, seat tube angle and the saddle-fore aft position as well as other factors on performance. As such it is important to include saddle height in this review for completeness and due to the difficulty in excluding from the discussion a key factor that is an integrated aspect of bike position.

The role of aerodynamics as an important determinant of speed in cycling is well established (Crouch et al., 2017). However, while acknowledging the vital role that aerodynamics plays in many cycling disciplines, the focus of this review is on the biomechanical and physiological aspects of cycling positioning, rather than the aerodynamics. We refer readers to a recent paper (Malizia & Blocken, 2021) that provides a comprehensive review of aerodynamics in cycling, including the effects of aspects of position and posture on aerodynamic drag.

Given the limitations of existing research, the aim of this paper is to complete a systematic review of the literature to identify factors related to bike position and configuration that influence cycling performance. Specifically, this systematic review sought to examine the role of trunk angle, handlebar height, Q factor, foot position, saddle fore-aft position, seat tube angle, crank length, saddle height and saddle tilt on cycling performance. Where possible, the review draws out differences for different cycling disciplines and differences for men and women. This paper is intended to be of particular value to bike fitting practitioners.

2. Methodology

This systematic review was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) recommendations (www.prisma-statement.org). The objectives, methodology and inclusion criteria for this paper were established in a protocol, which was prospectively registered online on OSF (https://osf.io/tw24z/).

2.1. Eligibility criteria

An initial limited search identifying index terms and keywords was conducted in December 2021 on Google Scholar and PubMed using the eligibility criteria set out in Table 1. The official initial search was performed on 5 January 2022, and finalised in January 2024 using the following databases: Embase, Web of Science, Medline (OVID) and CINAHL. The search included the general terms cycling, cycling position, bike fitting, bike position configuration (see Appendix E for full search terms).

The keyword combinations searched across databases included: cycling position, cycling position and efficiency, bike position configuration, physiology and biomechanics. Full details were exported to EndNote (Thomson Reuters, New York, USA) to allow importing of titles and abstracts into Covidence (Covidence, 2022). The PRISMA guidelines were applied to develop this systematic review and synthesise the results.

2.2. Study screening

Search results were compiled and screened for titles of relevance (using the consensus of researchers SHu and DC) on the Covidence platform. A total of 16,578 studies were imported for screening. Duplicates across databases were removed, resulting in 6827 relevant articles. Article titles and abstracts were screened by two reviewers (SHu and DC). Any conflicts were discussed and, where consensus was achieved, those studies that met the criteria were included. When a consensus was not reached, a member of the wider research team (CS) provided a casting vote (this occurred three times). In total, 173 titles were identified as relevant. Where relevant studies were not accessible, the authors were contacted to gain access. Full text was evaluated, removing a further 126 studies. The reference

Table 1. Inclusion and exclusion criteria for the journals included in the systematic review.

Inclusion Criteria	Exclusion Criteria
Peer-reviewed publications published in English	Non-peer reviewed publications
	Opinion pieces
	Papers not available in English
Study population of competitive cyclists, trained cyclists, and trained triathletes	Recreational cyclists
Provide empirical evidence	Reviews
Address cyclist position optimisation	Non-relevant articles (clinical populations, handcycling, recycling)
Related to traditional upright or time trial cycling	Duplicates
Related to the biomechanics and/or physiology of positional changes in cycling	Epidemiological articles
Position changes related to one or more of:	Full text of paper not available
Handlebar height	Seated vs Standing cycling studies
Saddle height	Bicycle gearing
Trunk angle	Chainring changes
Crank length	Uncoupled cranks
Saddle fore-aft	
Seat tube angle	
Q Factor	
Foot position	
Saddle tilt	

list of the included studies was also explored to identify additional relevant studies, resulting in an additional 11 eligible studies being included; these went through the same screening process as all included papers. The remaining 47 studies were used for the purpose of this systematic review (see Figure 1), originating from 14 countries (see Table A1, Appendix A). The significant drop in eligible studies from 6287 to 173 resulted in large part from the number of papers where "cycle" referred to unrelated topics in engineering & biology etc.

2.3. Data extraction

Following screening and study selection, a researcher (SHu) extracted the data from the included studies. An evidence table was created, which comprised of study title, author, aims and objectives, participant characteristics, data analysis methods and testing methods along with outcome measures and key findings. A second reviewer (DC) checked the extraction document, and any potential issues were addressed through discussion.

2.4. Quality and risk of bias assessment

PRISMA endorses screening and reporting the risk of bias assessment as part of the PRISMA 2020 Statement (Page et al., 2021). A search was performed to find the most applicable quality assessment tool for the types of studies identified during the screening process. All except one of the studies were nonrandomised interventional studies in design, comparing the outcome of an intervention with the pre-intervention measurement on the same participants. One study was a cross-sectional observational study. Considerations were given to a number of tools, including the AXIS (Downes et al., 2016) and ROBIS (Whiting et al., 2016) tools, before identifying the NIH (Ma et al., 2020) quality assessment tool as the most appropriate option. The studies were screened in accordance with the quality assessment tools from the National Heart, Lung, and Blood Institute (NIH) (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools) as recommended by Ma and colleagues (Ma et al., 2020). The NIH tools consist of questions that address the quality of each study in terms of its internal validity, including the risk of bias. However, the tool does not provide an overall rating against each criterion. Instead, the process allows the user to rate the study as 'good', 'fair' or 'poor' quality, indicating whether there has been a bias which may limit the accuracy or applicability of the outcomes of each study. To create a more quantifiable and standardised assessment the authors created a scoring matrix (Appendix B) that identified essential study characteristics using the responses to the tool questions that were required to achieve each of the three study ratings, with a separate assessment for the intervention studies and for the observational study included.

3. Results

3.1. Study characteristics

The results of the screening process are summarised in Table A2 (Appendix A), showing 47 studies successfully passed the screening process. The results yielded studies containing a total of 724 participants, of which 90 were female and 454 were male. For the remaining 180 participants the sex was not stated. Of the 47 studies, 18 investigated trunk angle/upper body position, 1 investigated handlebar height, 4 investigated Q factor, 3 investigated foot position, 4 investigated saddle fore-aft, 5 investigated seat tube angle, 4 investigated crank length and 10 investigated saddle height, with some overlap as some studies did not exclusively observe one component. There was no eligible study on saddle tilt. Road, time trial and mountain bike cycling were the disciplines of cycling as reported by the study methodology, see Table A3 (Appendix A). The components of configuration within each discipline are given in Table A4 (Appendix A). Discipline of participants refers to discipline of cycling the participants actively took part in, see Table A5 (Appendix A). Table A6 (Appendix A) shows the breakdown of sex distribution per configuration grouping, with some overlap as some studies did not exclusively observe one component, e.g., participants for handlebar height may also be the same participants for torso

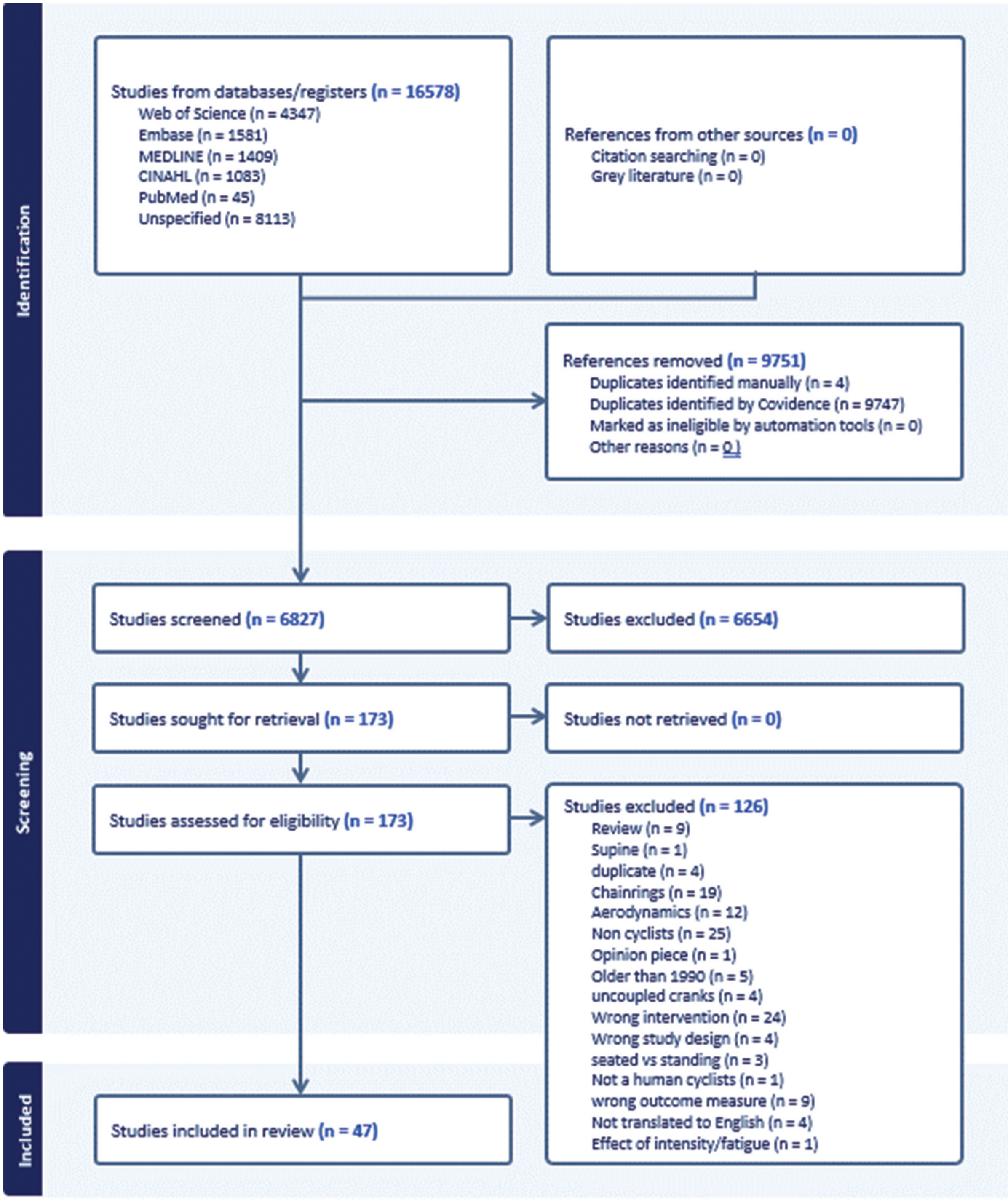

Figure 1. PRISMA flow chart.

angle. The distribution of studies that included riders exclusively of one sex were: 21 males only, 2 females only, with 12 investigating both males and females. The remaining 12 studies did not specify the rider's sex.

3.2. Quality and risk of bias assessment

The results of the outcomes of the quality and risk of bias assessment tool are shown in Table 2 for before-after studies with no control group and Table 3 for observational cohort and cross-sectional studies. Overall, they show 0 studies were rated "good", 5 rated "fair", 32 rated as "poor" and 10 could not be rated due to not meeting the criteria for the "poor" group.

Table A1 (Appendix A) provides a breakdown of the countries of origin. Of the 14 countries, the most common origin of studies was the USA with 11, followed by the UK with 10. The remaining countries published < 5 studies each. Strengths in the study design were identified as the objective of the study being clear (47 studies). Weaknesses in the study design are evident in several areas. These include inadequate justification

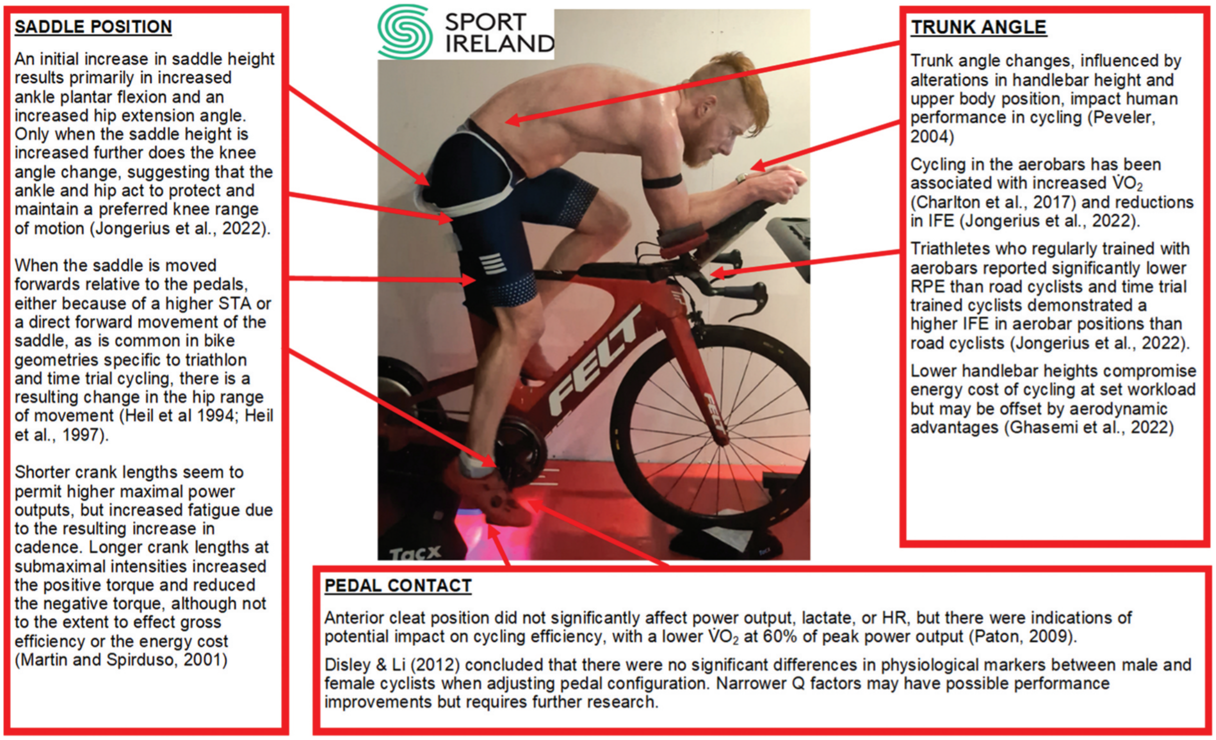

Figure 2. Summary of findings.

for the sample size, lack of blinding among assessors regarding the interventions, failure to measure outcome variables multiple times both before and after the intervention, and the absence of consideration for individual-level data in the statistical analysis, see Table 2. A definition of the assessment categories for the columns is given in Appendix B.

3.3. Trunk angle/upper body position

Eighteen studies observed the effect of changes in trunk angle and upper body position on kinematics, kinetics, muscle activation and ventilatory (HR, VO_2) measures (Bini et al., 2019; Charlton et al., 2017; Dorel et al., 2009; Fintelman et al., 2016; Franke et al., 1994; Hubenig et al., 2011; Jobson et al., 2008; Jongerius et al., 2022; Kordi et al., 2019; Peveler et al., 2004, 2005; Savelburg et al., 2003; Sheel et al., 1996; Skovereng et al., 2020; Welbergen & Clijsen, 1990; Wiggins et al., 2021). The studies investigating trunk angle included a total of 296 participants: 201 male, 32 female, 63 not specified. Twelve out of 18 studies reported the research discipline as road cycling, the remaining six studies investigated time trial cycling, see Table A3 and A4 (Appendix A).

Six studies investigating the effect of trunk angle/upper body position on joint kinematics (Bini et al., 2019; Jongerius et al., 2022; Savelburg et al., 2003; Skovereng et al., 2020; Wiggins et al., 2021). Bini et al. (2019) concluded that there were no significant changes to knee and ankle kinematics as a result of changing trunk angle. In contrast, Savelburg et al. (2003) concluded that the average angles for hip, knee and ankle changed significantly. Trunk angle significantly reduced when changing from the brake hood levers to the drops and reduced further when cycling in the aerobars (Jongerius et al., 2022; Skovereng et al., 2020). This was confirmed by Wiggins et al. (2021) who reported that cycling in the upright position resulted in 29° more hip extension than the aero position.

Nine studies investigated the effect of trunk angle/upper body position on kinetics (Bini et al., 2019; Fintelman et al., 2016; Hubenig et al., 2011; Jobson et al., 2008; Jongerius et al., 2022; Kordi et al., 2019; Peveler et al., 2004; Skovereng et al., 2020; Welbergen & Clijsen, 1990). One study concluded that power output is higher when cycling with a more vertical trunk angle when compared to a horizontal trunk (Welbergen & Clijsen, 1990). Similar findings were reported by Fintelman et al. (2016) that cycling with a fully horizontal back is not beneficial. Four studies concluded that power output was greater in the upright position when compared to the drops and aerobars (Hubenig et al., 2011; Jobson et al., 2008; Peveler et al., 2004; Skovereng et al., 2020). The remaining studies reported that mean power output was not affected by the upper body position (Kordi et al., 2019) and lowering of the trunk angle to reduce reduces power output and IFE (Jongerius et al., 2022).

Six studies investigated the effect of trunk angle/upper body position on muscle activation (Bini et al., 2019; Charlton et al., 2017; Dorel et al., 2009; Fintelman et al., 2016; Savelburg et al., 2003; Wiggins et al., 2021). The activation of gluteus maximus and vastus lateralis appeared to be later in the pedal stroke as the trunk angle reduced (Fintelman et al., 2016). The onset of muscle activation was not affected by the change in trunk angle. However, the bicep femoris, tibialis anterior and soleus contributed to more of the pedal stroke in a forward flexed position than in upright cycling (Savelburg et al., 2003). Bini et al. (2019) concluded the hip contributed less and the knee contributed more when lowering the trunk angle. Cycling in

Table 2. Results of the NIH risk of bias score: see appendix B for definition of assessment categories 1–12.

Study/Assessment category	1	2	3	4	5	6	7	8	9	10	11	12	Score
(Welbergen & Clijsen, 1990)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Franke et al., 1994)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Heil et al., 1994)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Sheel et al., 1996)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Heil et al., 1997)	Y	N	Y	CD	N	N	Y	N	N/A	Y	N	N	**Not rated**
(Price & Donne, 1997)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Garside & Doran, 2000)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Martin & Spirduso, 2001)	Y	N	Y	CD	N	N	Y	N	N/A	Y	N	N	**Not rated**
(Savelburg et al., 2003)	Y	N	Y	CD	N	N	Y	N	N/A	Y	N	N	**Not rated**
(Peveler et al., 2004)	Y	Y	Y	CD	N	Y	Y	N	N/A	Y	N	N	**Fair**
(Peveler et al., 2005)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Van Sickle & Hull, 2007)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Peveler et al., 2007)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Jobson et al., 2008)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Peveler, 2008)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Dorel et al., 2009)	Y	Y	Y	CD	N	Y	Y	N	N/A	Y	N	N	**Fair**
(Paton, 2009)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Macdermid & Edwards, 2010)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Tomas et al., 2010)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Hubenig et al., 2011)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Peveler & Green, 2011)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Vrints et al., 2011)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Disley & Li, 2012)	Y	Y	Y	CD	N	N	N	N	N/A	N	N	N	**Poor**
(Bisi et al., 2012)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Bini et al., 2013)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Connick & Li, 2013)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(R. Bini, P. Hume, & A. E. Kilding, 2014)	Y	N	Y	CD	N	N	Y	N	N/A	Y	N	N	**Not rated**
(Disley & Li, 2014)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Ferrer-Roca et al., 2014)	Y	N	Y	CD	N	Y	Y	N	N/A	N	N	N	**Not rated**
(Fintelman et al., 2016)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Harper et al., 2014)	Y	Y	Y	CD	N	Y	Y	N	N/A	Y	N	N	**Fair**
(Diefenthaeler et al., 2018)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Fintelman et al., 2016)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Menard et al., 2016)	Y	N	Y	CD	N	Y	Y	N	N/A	Y	N	N	**Not rated**
(Charlton et al., 2017)	Y	Y	Y	CD	N	N	N	N	N/A	Y	N	N	**Poor**
(Ferrer-Roca et al., 2017)	Y	N	Y	CD	N	Y	Y	N	N/A	Y	N	N	**Not rated**
(Bini et al., 2019)	Y	Y	Y	CD	N	Y	N	N	N/A	Y	N	N	**Poor**
(Bini et al., 2019)	Y	N	Y	CD	N	N	N	N	N/A	Y	N	N	**Not rated**
(Kordi et al., 2019)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Menard et al., 2020)	Y	Y	Y	CD	N	Y	Y	N	N/A	Y	N	N	**Fair**
(Skovereng et al., 2020)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Millour et al., 2021)	Y	N	Y	CD	N	Y	Y	N	N/A	Y	N	N	**Not rated**
(Wiggins et al., 2021)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Chartogne et al., 2022)	Y	Y	Y	CD	Y	Y	Y	N	N/A	Y	N	N	**Fair**
(Ghasemi et al., 2022)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**
(Jongerius et al., 2022)	Y	Y	Y	CD	N	N	Y	N	N/A	Y	N	N	**Poor**

Table 3. Results of the NIH risk of bias score for observational cohort and cross-sectional studies: see appendix B for definition of assessment categories 1–14.

Study/Assessment category	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Score
(Holliday & Swart, 2021)	Y	Y	NR	Y	N	NA	NA	NA	N	NA	N	N	NA	NA	**Not rated**

the aerobars induced higher muscle activity of gluteus maximus, vastus lateralis and vastus medialis, whereas the upright position induced a higher muscle activity of rectus femoris (Dorel et al., 2009). In contrast, Wiggins et al. (2021) concluded that body position had no impact on the activation of vastus lateralis.

Ten studies investigated the effect of trunk angle/upper body position on ventilatory responses and energy cost (Charlton et al., 2017; Dorel et al., 2009; Fintelman et al., 2016; Franke et al., 1994; Hubenig et al., 2011; Jobson et al., 2008; Peveler et al., 2005; Sheel et al., 1996; Welbergen & Clijsen, 1990; Wiggins et al., 2021). Mean minute ventilation, breathing frequency and VO_2 were shown to significantly increase when lowering trunk angle, causing a decrease in gross efficiency (Fintelman et al., 2016). Cycling in the drops and aerobars showed a significant reduction in VO2, HR and VE compared to the brake hood levers (Charlton et al., 2017; Sheel et al., 1996). In contrast, VO_2 and HR were increased when cycling in the aerobars (Peveler et al., 2005; Wiggins et al., 2021).

3.4. Handlebar height

One study of seven male participants observed the effect of changes in handlebar height on ventilatory (HR, VO_2) measures (Ghasemi et al., 2022). The research discipline was reported as road cycling (Ghasemi et al., 2022), see Table A3 (Appendix A). Ghasemi et al. (2022) found VO_2, RER and VE increased at lower handlebar positions.

3.5. Q factor

Four studies observed the effect of changes in Q Factor on kinematic, muscle activation and ventilatory (HR, VO_2) measures (Disley & Li, 2012, 2014; Harper et al., 2014; Millour et al., 2021). The studies of Q Factor included a total of 67 participants: 27 male, 18 female and 22 not specified. All four studies reported the research discipline as road cycling, see Table A3 (Appendix A).

Three studies investigated the effect of Q Factor on joint kinematics (Disley & Li, 2012, 2014; Millour et al., 2021). There were no significant differences between the different configurations for hip and knee kinematics in the frontal and transverse planes (Millour et al., 2021). It was reported that knee stability is decreased when cycling with SSQ-30 mm and SSQ +30 mm when compared to SSQ (Disley & Li, 2014).

Two studies investigated the effect of Q Factor on muscle activation (Disley & Li, 2012; Millour et al., 2021) and found that Q factor did not affect the mean muscle activity during cycling (Millour et al., 2021). The muscles in the lower limb were recruited at the same point in the pedal stroke irrespective of Q factor (Disley & Li, 2012).

All four studies investigated the effect of Q Factor on ventilatory responses (Disley & Li, 2012, 2014; Harper et al., 2014; Millour et al., 2021). Cycling with a spindle 60 mm more than a standard road bike results in higher VO_2 and HR but decreased gross efficiency (Millour et al., 2021). Similar findings were reported by Disley and Li (2012) who concluded that gross mechanical efficiency was higher when cycling with a smaller Q factor of 90 mm in comparison to the larger Q factors. In contrast, two studies concluded that the lateral placement of the pedal did not significantly change cycling performance. Harper et al. (2014) found that VO_2, HR, RER and maximal power were not significantly impacted when comparing a short spindle of 15 mm and long spindle of 32 mm.

3.6. Foot position

Three studies observed the effect of changes in foot position on kinematic, kinetic, muscle activation and ventilatory (HR, VO_2) measures (Chartogne et al., 2022; Paton, 2009; Van Sickle & Hull, 2007). The studies of foot position included a total of 33 participants: 19 male, 2 female, 12 not specified. All three studies reported the research discipline as road cycling, see Table A3 (Appendix A).

One study investigated the effect of foot position on joint kinematics (Chartogne et al., 2022). Shoe-cleat cleat position affected hip extension, but only by 1.5° and this did not significantly alter hip flexion or ROM. Knee and ankle kinematics (flexion and extension) were affected by the alterations in shoe-cleat position, however this did not affect ROM for knee or ankle (Chartogne et al., 2022).

Two studies investigated the effect of foot position on kinetics (Paton, 2009; Van Sickle & Hull, 2007). Foot position did not significantly affect kinetic outcomes across the different configurations for submaximal cycling (Paton, 2009; Van Sickle & Hull, 2007) or sprint cycling (Chartogne et al., 2022).

Three studies investigated the effect of foot position on muscle activation (Chartogne et al., 2022; Paton, 2009; Van Sickle & Hull, 2007). Foot position did not significantly affect EMG outcomes across the different configurations for submaximal cycling (Paton, 2009; Van Sickle & Hull, 2007) or sprint cycling (Chartogne et al., 2022).

Three studies investigated the effect of foot position on ventilatory responses (Chartogne et al., 2022; Paton, 2009; Van Sickle & Hull, 2007). Foot position did not significantly affect ventilatory outcomes across the different configurations for submaximal cycling (Paton, 2009; Van Sickle & Hull, 2007) or sprint cycling (Chartogne et al., 2022). However, Paton (2009) noted that oxygen uptake at 60% of peak power output was lower when the cleat was under the arch of the foot, indicating that foot position in the cleat may play a role in the energy cost of cycling.

3.7. Saddle fore-aft

Four studies observed the effect of changes in saddle fore-aft position on kinematics, kinetics and power output (Bini et al., 2013; Menard et al., 2016, 2020; Vrints et al., 2011). The studies investigating saddle fore-aft included 52 participants: 31 male, 0 female and 21 not specified. All four studies reported the research discipline as road cycling.

Vrints et al. (2011) did not find any effect of changes in the fore-aft position of the saddle on the peak power produced during isokinetic 5-s sprints. Menard et al. (2016) observed that IFE and the index of work effectiveness were higher at the more backward saddle positions in comparison to the forward positions during submaximal cycling.

Investigating the effect of saddle fore-aft position on joint forces, Bini et al. (2013) observed that the saddle set back had no effect on the patellofemoral or tibiofemoral compression forces, but the backward position increased the anterior tibiofemoral shear force. Menard et al. (2020) found that although there was no significant effect of saddle fore-aft position on the mean or peak knee patellofemoral forces in any of the directional components, there were larger mean and peak tibiofemoral compression forces in the backward in comparison to the forward saddle position, contrary to some of the findings of Bini et al. (2013).

3.8. Seat tube angle

Five studies (Bisi et al., 2012; Garside & Doran, 2000; Heil et al., 1994, 1997; Price & Donne, 1997) observed the effect of changes in seat tube angle (STA) on kinematic, kinetic, muscle activation and cardiorespiratory (HR, VO_2) measures. The studies investigating seat tube angle included 71 participants: 64 male and 7 female. Three out of five studies reported the research discipline as road cycling, while the remaining two studies investigated time trial cycling. Higher STA (e.g., 90°) resulted in a steeper and more forward saddle position relative to the bottom bracket. This geometry configuration is common in time trial and triathlon bikes where low trunk angles and aerobars are used to reduce drag forces.

Three studies investigated the effect of STA on joint kinematics (Bisi et al., 2012; Heil et al., 1994, 1997). Mean trunk angle remained unchanged between the trials of different STAs (Heil et al., 1994). As STA increased, there was an increase (5°) in mean hip extension angle (Heil et al., 1994, 1997) and a small increase (1°) in ankle plantar flexion (Heil et al., 1994), whilst knee angles remained unchanged (Heil et al., 1994, 1997). Notably, the whole lower body oriented more directly over the crank axis with steeper (higher) STAs. However, Bisi et al. (2012) found no difference in kinematics for the hip, knee or ankle when investigating STAs. One study investigated the effect of STA on muscle activation. A higher STA (78° vs 73.4°) was associated with lower activation of the gastrocnemius and bicep femoris (Bisi et al., 2012).

Five studies investigated the effect of STA on cardiorespiratory responses. Three studies reported that VO_2 and HR were higher when cycling with a smaller STA (Heil et al., 1994, 1997; Price & Donne, 1997). However, the remaining two studies concluded that altering the STA had no effect on the VO2, HR, RER or blood lactate (Bisi et al., 2012; Garside & Doran, 2000),

3.9. Crank length

Four studies observed the effect of changes in crank length on kinematic, kinetic and ventilatory measures (Ferrer-Roca et al., 2017; Macdermid & Edwards, 2010; Martin & Spirduso, 2001; Tomas et al., 2010). The studies investigating crank length included a total of 35 participants: 16 male, 7 female and 12 not specified. Three out of four studies reported the research discipline as road cycling, and the remaining study investigated mountain bike cycling, see Table A3 (Appendix A).

Martin and Spirduso (2001) reported that 145 mm and 170 mm cranks produced the highest maximum power output when sprinting over 4 s, when compared to 120 mm and 220 mm cranks, but there was only a 4% variation in maximum power across the range of crank lengths. While the cadence associated with the maximum power at each crank length decreased with crank length, the pedal speed actually increased due to the larger distance travelled by the pedal. Macdermid and Edwards (2010) measured a range of endurance and maximum power-related measures and found only a difference in the time to peak power, which was shorter with 170 mm compared to 175 mm cranks. Tomas et al. (2010) found no difference in peak power between crank lengths of 120 mm and 220 mm, but the shorter cranks resulted in a higher cadence which in turn created a higher fatigue index during 30 s of all-out cycling. Smaller changes in crank length of ±5 mm in comparison to the preferred crank length had no effect on HR, cadence or Gross Efficiency during submaximal cycling (Ferrer-Roca et al., 2017). However, the longer cranks resulted in an increased maximum torque, decreased minimum torque and increases in the ROM at the knee and hip.

3.10. Saddle height

Ten studies observed the effect of changes in saddle height on kinematic, kinetic, muscle activation and ventilatory (HR, VO_2) measures (R. Bini, P. Hume, & A. E. Kilding, 2014; Connick & Li, 2013; Diefenthaeler et al., 2018; Ferrer-Roca et al., 2014; Holliday & Swart, 2021; Peveler, 2008; Peveler & Green, 2011; Peveler et al., 2007; Price & Donne, 1997; Vrints et al., 2011). The studies investigating saddle height included a total of 187 participants: 114 male, 23 female and 50 not specified. All 10 of the saddle height studies reported the research discipline as road cycling, see Table A5 (Appendix A).

Eight studies measured the changes in joint kinematics with changes in saddle height (Bini et al., 2013; Connick & Li, 2013; Ferrer-Roca et al., 2014; Holliday & Swart, 2021; Peveler, 2008; Peveler & Green, 2011; Peveler et al., 2007; Vrints et al., 2011). A decrease in saddle height was associated with increased knee flexion, increased hip flexion (Bini et al., 2012; Ferrer-Roca et al., 2014; Vrints et al., 2011) and reduction in ankle plantar flexion (Ferrer-Roca et al., 2014). Peveler et al. (2007) concluded that a saddle height of 109% IL generated a KFA that fell within the recommended range 37% of the time.

Five studies investigated the effect of saddle height on peak power/torque and pedalling kinetics (Bini et al., 2010; Connick & Li, 2013; Diefenthaeler et al., 2018; Peveler & Green, 2011; Vrints et al., 2011). Vrints et al. (2011) concluded that the lowest maximal power was associated with a lower saddle position. This was confirmed by another study (Peveler & Green, 2011) which reported that peak power output was significantly greater at a knee extension angle of 25° compared to 35° and saddle height of 109% IL. Diefenthaeler et al. (2018) found no impact of saddle height on the peak torque measured between TDC and BDC. Although asymmetry was present, it was unaffected by saddle height. Bini et al. (2011) observed an increase in IFE (7% in cyclists, 2% in triathletes) when increasing saddle height from preferred to optimal (25° knee extension angle at BDC), with no differences between the cyclists and triathletes at the optimal saddle height. One study observed the effects of saddle height on muscle activation patterns (Connick & Li, 2013). Increases in saddle height from 96% to 100% TH altered the timing and duration of eccentric bi-articular muscle contractions during cycling. While there were small differences in the eccentric contractions of the gastrocnemius, vastus lateralis and biceps femoris during the propulsion phase of the pedal stroke with saddle height, these changes had no effect on the oxygen cost.

Five studies (Connick & Li, 2013; Ferrer-Roca et al., 2014; Peveler, 2008; Peveler & Green, 2011; Price & Donne, 1997) observed the effect of saddle height on the oxygen demand of cycling. Price and Donne (1997) found that VO_2 was greater when the saddle height was increased from 96% to 104% TH. RocaFerrer-Roca et al. (2014) recorded that the oxygen consumption was lower at a saddle height 2% lower than the participants' preferred saddle height in comparison to a position 2% higher than their preferred height. Peveler (2008) and Peveler and Green (2011) found that the oxygen cost was lower with a saddle height set to create a knee flexion angle at BDC of 25° (higher saddle), compared to 35° (lower saddle) or 109% IL. Connick and Li (2013) found no differences in oxygen demand between saddle heights set at 96%, 98% and 100% TH. Gross Efficiency was determined in one study, where Ferrer-Roca et al. (2014) found that Gross Efficiency was improved at a saddle height set as 2% lower than the preferred saddle height in comparison to the 2% higher position.

At odds to their findings on submaximal cycling, Peveler and Green (2011) found that the 109% of IL saddle height produced greater mean power over 30 s than the other positions, but peak power was greatest at the 25° knee flexion angle saddle height position.

4. Discussion

While there has been extensive research on saddle height, as evidenced by a recent review by Bini and Priego-Quesada (2022), other positional aspects have not received the same level of investigation. Since cycling is affected by many positional factors, the present review seeks to gather and summarise the most significant discoveries from prior research, with a specific focus on addressing the existing knowledge gap in optimising cycling posture. It encompasses studies involving competitive and well-trained cyclists or triathletes. Currently, research beyond saddle height shows little consensus for the other bike configuration variables with a large variation in volume and quality of published studies. Moreover, a common issue in this field is the frequent segregation of biomechanical and physiological outcome measurements. This division makes it challenging to definitively determine an ideal configuration, especially when the additional factors of sex and cycling discipline have not been taken into consideration. We have collated the key findings to assist the bike fitting practitioner understand the known effects of changes in factors related to bike position and configuration on aspects of cycling performance.

4.1. Trunk angle/upper body position (results sections 3.3 & 3.4)

It is clear that trunk angle changes, influenced by alterations in handlebar height and upper body position, do impact human performance in cycling (Peveler et al., 2004). Additionally, cycling in the aerobars has been associated with increased VO_2 (Charlton et al., 2017), and reductions in IFE (Jongerius et al., 2022). The increase in energetic cost is mainly attributed to the loss of breathing efficiency and reductions in IFE. Lower handlebar heights also compromise the energy cost of cycling at a set workload, but this may be offset by the aerodynamic advantages of these positions.

Trunk angle studies show different results for time trial compared to road cycling. Triathletes who regularly trained with aerobars reported significantly lower RPE than road cyclists (Peveler et al., 2005) and time trial trained cyclists demonstrated a higher IFE in aerobar positions than road cyclists (Jongerius et al., 2022). Aligned with these outcomes, road cyclists exhibited significantly higher VO_2 in the aerobar position, suggesting increased cardiorespiratory demands when cycling in this position. The results from these different studies, suggest that both careful positioning and regular training in the aerobar position may lead to improved performances in time trial events due to a lowered oxygen cost and increased IFE.

4.2. Pedal contact (results sections 3.5 & 3.6)

Research on the Q factor has yielded mixed results (Disley & Li, 2012, 2014), although wider Q factors seemed to decrease gross efficiency. However, some studies indicated that anterior cleat position did not significantly affect power output, lactate or HR, but there were indications of potential impact on cycling efficiency, with a lower VO_2 at 60% of peak power output (Paton, 2009). Foot position did not significantly affect muscle activation or kinetic outcomes in submaximal or sprint cycling. This is probably because foot position mostly affects the ankle angle, which may compensate its position for stability to transfer force effectively to the pedals (Bini et al., 2010).

All of the seven studies of pedal contact focused on road cycling, and only three specified that they involved participants who regularly train in the intended research discipline. Disley and Li (2012) concluded that there were no significant differences in physiological markers between male and female cyclists when adjusting pedal configuration. However, no studies focused solely on women, so further studies on pedal contact in disciplines other than road cycling and more studies with women participants are needed. The impact of Q Factor on cycling performance and the notable morphological differences between sexes, such as females having a greater Q angle at the hips (Tillman et al., 2005), is a motivation for this research.

The adoption of an anterior cleat position may reduce the oxygen cost of cycling, but there appears to be no clear effect of changes in cleat position. Overall wider Q factors are associated with an increased energy cost, and therefore, the choice to use wider Q factors should be made carefully.

4.2.1. Saddle position (results sections 3.7, 3.8, 3.9 & 3.10)

The effective saddle position is influenced by saddle height, fore-aft adjustment, STA and crank length. Broadly, the observed saddle height in road cyclists has been found to be moderately associated with leg length, hamstring flexibility and lumbar flexibility (Holliday & Swart, 2021). However, when the saddle position is moved relative to other contact points on the bike, via the saddle height, STA or saddle fore-aft, this results in subtle and often variable changes. The change in kinematics is the clearest response reported. An initial increase in saddle height results primarily in increased ankle plantar flexion and an increased hip extension angle. Only when the saddle height is increased further does the knee angle change, suggesting that the ankle and hip act to protect and maintain a preferred knee range of motion (Jongerius et al., 2022). When the pedal to saddle distance decreases the opposite occurs, with increases in ankle dorsiflexion and decreases in the hip extension angles. When the saddle is moved forwards relative to the pedals, either as a result of a higher STA or a direct forward movement of the saddle, as is common in bike geometries specific to triathlon and time trial cycling, there is a resulting change in the hip range of movement (Heil et al., 1994, 1997). The increase in hip extension acts to facilitate a lower torso angle, which reduces the frontal area in these disciplines, again demonstrating the fundamental interconnectedness of the effects of changing positional variables. Relatively higher saddle positions, creating knee flexion angles at BDC of 25° seem to result in higher peak power outputs, although this review only found two studies (Peveler & Green, 2011; Vrints et al., 2011) investigating this aspect of cycling performance. Changes in the energy cost of cycling and the IFE are less clear in response to the saddle position. In general, higher saddle positions carry a greater energy cost of cycling, although there seems to be a variation in response at the individual level. The IFE improved with relatively higher and backward saddle positions, likely due to the increased range of motion available at the ankle to better direct forces at the pedal to contribute more effectively to torque acting at the bottom bracket (Menard et al., 2016). Shorter crank lengths seemed to permit higher maximal power outputs, but increased fatigue due to the resulting increase in cadence. Longer crank lengths at submaximal intensities increased the positive torque and reduced the negative torque, although not to the extent to affect gross efficiency or the energy cost. Changes to crank lengths result in changes to the kinematics and the ROM at the hip and knee, but these are subtle and may not greatly influence submaximal performance. The role of saddle position on internal joint forces at the knee is not clear, with Bini et al. (2013) reporting no increase in tibiofemoral compression forces, while Menard et al. (2020) recorded an increase in the tibiofemoral compression forces.

Most studies of saddle position addressed road cycling, and male participants, with only two explicitly involving participants who regularly train in the specified research discipline. Thus, while Peveler et al. (2007) and Peveler (2008) concluded that there were no significant differences in physiological markers between male and female cyclists when adjusting bike configuration, further researcher is needed to assess sex, discipline and training level effects.

4.3. Cycling discipline

Road cycling was by far the most studied discipline. Time trial cycling was the focal point in only one study and triathlon cycling was addressed in four studies. The cycling discipline of the participants was often not reported. This highlights the need for more specificity and comprehensive research on potential changes within various cycling disciplines, such as mountain biking, road cycling, time trial cycling and track cycling. The individual demands associated with different disciplines are often not acknowledged in existing studies. Consequently, future research should investigate positional optimisation specific to the events within each discipline of cycling, as each is constrained by its own UCI regulations and specific priorities for handling, aerodynamics, power production and comfort (UC2022.

4.4. Sex

Currently, there is a limited emphasis on studying the positioning of women cyclists, see Table A7 (Appendix A). Of all the included studies, only four directly compared the sexes. Additionally, only two exclusively observed the impact of body positioning changes in cycling in females (Hubenig et al., 2011; Macdermid & Edwards, 2010). There is thus clearly an underrepresentation of women across all positional configuration studies. Addressing this gap in future research is essential in order to develop an improved understanding of how position can be optimised for women, especially in aspects of position where they may differ anatomically or functionally compared to their male counterparts. Studies directly comparing men's to women's positions are needed to better understand differences in cycling positions between the sexes.

4.5. Drag effects

This review focussed on performance related to biomechanics and physiology, but clearly reducing drag is a major additional component in many cycling scenarios. Understanding factors that determine drag for cyclists is a large area of cycling research and is beyond the scope of the present review. Research on drag focuses mostly on wind tunnel testing and computational fluid dynamics and is the subject of an excellent recent review (Malizia & Blocken, 2021). This research identifies the importance of the cyclist's frontal area and three-dimensional shape as being key factors that influence the coefficient of drag and the resulting aerodynamic resistive forces. Both of these factors can be substantially influenced and altered by changing the trunk angle. Trunk angle has been included in the present review purely from a biomechanical and physiological standpoint as lowering of the trunk angle to reduce drag has been shown to reduce power output and IFE, and increase physiological variables such as oxygen uptake and minute ventilation when compared to upright cycling (Hubenig et al., 2011; Jongerius et al., 2022; Peveler et al., 2004). Therefore, taking into account the biomechanical and physiological changes that take place alongside the aerodynamic changes is important when considering the trunk angle as a means to influence cycling performance.

5. Limitations

Each leg of the rider and bike might be considered as a planar closed kinematic chain with two degrees of freedom, such that for any given crank position, even assuming a fixed pelvis orientation, the knee and hip angles are not uniquely determined unless the ankle angle is also known (Hull & Jorge, 1985). For the upper body, the practice of modelling the trunk as a straight-line segment from the hips to the shoulders (see Appendix D) does not capture the effects of spinal curvature which can affect aerodynamic drag and minute ventilation (Peveler et al., 2004). The research shows that most positional changes have interactive effects on the relevant biomechanical and physiological variables. Furthermore, anthropometric and physiological variations between individuals are significant, and as a result, despite many studies addressing individual positional effects on cycling performance, there are no accepted optimal positional recommendations with widespread application across different cycling populations.

The papers in this review overwhelmingly addressed conventional upright and time trial cycling, with only one paper investigating mountain bike cycling. It did not identify any research that distinguished optimal positioning variations across various cycling disciplines. Additionally, there was a scarcity of papers examining women cyclists within the scope of this review. Furthermore, the justification for the sample size in the included studies was infrequently provided, and in many cases the studies may be under-powered (Mesquida et al., 2023). Of the 47 studies included only 4 (Heil et al., 1994; Holliday & Swart, 2021; Jongerius et al., 2022; Peveler et al., 2007) included more than 25 participants. Given different cycling disciplines impose unique biomechanical and physiological demands, incorporating participants who actively engage in the relevant discipline enhances the study's internal validity and practical application for the intended population. It is crucial to acknowledge that the scope of this systemic review is limited by the concentration of research primarily originating from the USA and the UK. Having an overwhelming majority of studies from a few countries may result in outcomes that lack representativeness on a global scale, particularly in the context of cycling. To mitigate potential bias in the review, research from a broader array of countries and ethnicities should be undertaken.

This systematic review reveals discrepancies in the increments applied to the configuration of saddle height, saddle fore-aft and STA. The observed inconsistencies involve a small range of increments, excessively large increments, or uneven adjustments. All of these factors pose challenges in identifying the magnitude of effects of positional changes on optimal configuration, though these would in any case be variable at an individual level. Accordingly, a statistical meta-analysis as recommended by the recent PERSiST paper (Ardern et al., 2022) was not feasible due to the heterogeneous nature of the data collection methods in the papers reviewed.

Many studies have explored saddle height measures, but a limitation lies in the inconsistency of methods used, such as a percentage of TH or IL, both being different anatomical sites and in addition different percentage-based methods of these sites have been used, adding to further inconsistency in the literature. Furthermore, language and knee angle definitions have sometimes been inconsistent throughout the body of existing research, which can lead to a lack of clarity.

Although studies report large within group variation, which may affect clear statistical outcomes when associated with small sample sizes, no studies examine the variation of individual responses to changes in position. When examining the group responses, it is clear that a variation in response across the group occurs in many cases, and understanding more about the responses and the set of circumstances that may cause cyclists to respond differently to positional interventions would be important for bike fitters.

No studies have assessed the time-dependent effects of positional changes. Given the recognised effects of human adaptation in other sports, this should be a focus for the future.

6. Recommendations for future research

Despite the volume and breadth of research undertaken by research teams to date, to whom practitioners and scientists in the field of cycling biomechanics are indebted, the outcomes of this review reveal that there are still large gaps in knowledge that limit the quality and efficacy of bike fitting. In general, an increase in both the inclusion of women participants in research studies and research specifically to identify any bike fitting-related differences between men and women is required. In addition, research should focus on developing an increased knowledge of cycling discipline-specific effects, effects of the Q factor, crank length, and the position of cleats on cycling shoes. This review has identified the interactive effects of a change in one contact point on the movement and function of a number of interconnected joints and limbs. From this perspective, more research should focus on the relationship between saddle fore-aft movements and the effects on the pelvis orientation and aspects of the trunk angle such as spinal curvature in addition to overall trunk angle. Research has identified the importance of the trunk angle on aerodynamics and cycling performance, however there is a limited understanding of the interaction between the combined effects of trunk angle, or other positional changes, on both the aerodynamics and the ability to generate and sustain power. Evaluating the effects of positional changes through the lens of both subcomponents of performance would further inform bike fitting practices. Research methodologies should also consider comparing the acute adaptations to positional changes in comparison to those chronic adaptations which might take place over a longer intervention period. While this approach may require increased study duration, the outcomes may have much greater application. While some research analysed biomechanical changes at a range of cycling intensities very few examined the effects at intensities specific to race intensities, limiting its direct relevance to competition. The same can be said of the effects of fatigue on the kinematics and kinetics and the role of changes of position to offset or minimise any negative effects. The development of new measurement technologies such as inertial measurement units, marker less kinematics and on-bike coefficient of drag area instrumentation, offers future research opportunities for outdoor monitoring resulting in research outcomes with increased ecological validity and relevance. This review did not exclusively search for tandem related studies however, the search terms yielded no results on this form of cycling. This highlights the need for more research on tandem specific optimisation as the interactive effects of the stoker and pilot are not well understood in terms of optimal aerodynamic and biomechanics.

7. Conclusion

We aimed to inform the bike fitting practitioner and researchers by completing a systematic review of the literature to assess and evaluate the effect of changes in factors related to bike position and configuration on aspects of cycling performance. Providing clear guidance for all cycling distances and disciplines of cycling for both sexes is not possible due to the limitations of the available research, most of which is based on road cycling and male participants. As such, discipline and sex-specific outcomes are generally not available.

It is clear however, that small changes to aspects of the cycling position initiate a series of kinematic changes which may influence the energy cost, power production, pedalling effectiveness and joint forces depending on the exact nature of the changes made. These outcomes illustrate the importance of a bike fitting process that is carefully conducted using validated measurement tools and an evidence-informed approach. There is a broad consensus that the dynamic knee flexion angle at bottom dead centre should be between 25° and 35° depending on whether maximum power or energy efficiency is a priority. The saddle fore-aft position may influence pedalling effectiveness, pelvic orientation and knee joint internal forces.

The trunk angle, which plays a critical role in aerodynamics, has been found to influence peak power output, oxygen cost and pedalling effectiveness. However, regular training in the aerobar position has been found to negate some of the functional disadvantages of this position.

Due to the limitations of the research identified during this review, there are no clear recommendations for crank length, handlebar height, Q factor or cleat position. A number of areas for future research have been identified as well as the limitations of the current body of research. See Figure 2 for a summary of findings.

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Data availability statement

All data collected or analysed during this review are included in this published article.

ORCID

Sean Philip Husband http://orcid.org/0000-0003-4746-2520

Ethical approval

As only published data were pooled, this research was exempt from local ethical approval.

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