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The impact of minor crank length adjustments on lower body cycling kinematics

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ABSTRACT

This study examined the effect of minor crank length adjustments on lower body cycling kinematics and exercise tolerance. Fourteen amateur cyclists performed sub-maximal cycling trials with five different crank lengths, preferred (165.0–172.5 mm), ±5 and 10 mm. An RPE prescription method determined intensity, and three-dimensional kinematics were collected using Vicon motion capture. Statistical parametric mapping was employed to analyse lower body kinematics. Changes in crank length had no effect on the mean power output (199.1 ± 50.5 W). However, minor reductions were associated with significant decreases in knee (0–24%; 58–100%) and hip (0–13%) flexion as well as increases in the anterior pelvic tilt (0–40%; 74–100%). Additionally, shorter cranks resulted in less pelvic obliquity and rotation, hip abduction and knee rotation. Minor reductions in crank length can decrease hip and knee flexion, can limit non-sagittal plane motion and could serve as an effective bike manipulation to reduce the risk of overuse injury. Shorter cranks also enable riders to achieve anterior pelvic tilt and could limit stress on the lumbar spine. As minor adjustments did not impact power output, crank length alterations should be considered during bike fits and by bike manufacturers.

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Cycling; crank length; biomechanics; statistical parametric mapping

Introduction

In cycling, to optimise a rider's position and subsequently increase performance, comfort and reduce injury risk, several alterations can be made to a bike. Factors such as saddle height, setback and tilt (Bini et al., 2011), cleat position (FitzGibbon et al., 2016), stem length and orientation (Swart & Holliday, 2019) and handlebar height (Holliday & Swart, 2021) have all been shown to influence a rider's position and pedalling technique. Saddle height has been the subject of the most research, with evidence suggesting a higher than optimal saddle decreases an athlete's ability to produce power (Sanderson & Amoroso, 2009) and increases VO_2 output (Peveler et al., 2005). Excessive saddle height has also been associated with anterior knee pain (Bini et al., 2011) and lower back injuries (Leavitt & Vincent, 2016) whilst a lower than optimal saddle can place too much stress on the patellar and quadriceps tendons (Asplund & St Pierre, 2004; Bini et al., 2011).

Crank length, the distance from the centre of pedal axle to the centre of the crank axle is another factor which can be manipulated to optimise a rider's position (Ferrer-Roca

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et al., 2017). Research has explored the effect of crank length alterations on the production of maximal short-term power, and it is generally agreed that shorter cranks significantly reduce the time to reach peak power (Barratt et al., 2011; Macdermid & Edwards, 2010). However, conflicting evidence exists regarding the magnitude of the peak power that can be achieved with different length cranks (Macdermid & Edwards, 2010; Too & Landwer, 2000). This may be due to the large variation in crank lengths examined (145–265 mm). When crank lengths (165–175 mm) which are representative of those used by most cyclists (Wadsworth & Weinrauch, 2017) have been examined, alterations do not appear to affect maximum power, joint-specific power production or the relative joint power contributions of the hip, knee and ankle (Barratt et al., 2011).

The effect of crank length alteration on sub-maximal cycling performance is more equivocal, with most studies (Ferrer-Roca et al., 2017; McDaniel et al., 2002) suggesting that over a wide range of crank lengths (145–195 mm), the energy cost of cycling remains stable. Over a similarly large range (150–190 mm), crank length manipulation also had no effect on sub-maximal power production strategies of the lower body (Barratt et al., 2016). Despite these similarities, large increases in crank length have been shown to increase the maximum hip and knee flexion and subsequently the range of motion at these joints in both supra-maximal (Too & Landwer, 2000) and sub-maximal (Barratt et al., 2016) cycling.

Similar findings at the hip and knee have been reported when smaller variations (5 mm from preferred crank length) in crank length were examined (Ferrer-Roca et al., 2017). An increase in maximum knee flexion caused by longer cranks has been related to patellofemoral compression force (Bini et al., 2010) and anterior knee pain (Asplund & St Pierre, 2004) – one of the most prevalent overuse injuries in cycling (Clarsen et al., 2010). Increased hip and knee flexion coupled with frontal plane rotations at these joints have the potential to further increase the risk of injury (Johnston et al., 2017). However, the effects of crank length alterations have only been examined in the sagittal plane and have only considered discrete events such as peak flexion angle and the range of motion (ROM) at each joint. Examinations of crank length in sub-maximal cycling have also neglected pelvis kinematics, which can have performance enhancing effects (Sauer et al., 2007) but have also been associated with increased injury risk (Farrell et al., 2003). Finally, crank length alteration has only been examined at generic power outputs which are not necessarily indicative of an individual's capabilities (Ferrer-Roca et al., 2017).

Therefore, the purpose of this study was i) to examine the impact of minor crank length adjustments on lower body cycling kinematics and ii) to explore the effect of crank length adjustment on exercise tolerance and power output. With this in mind, we set two hypotheses: i) minor increments in crank length would lead to increased lower body joint flexion around the top of the pedal stroke and contribute to greater non-sagittal plane motion and ii) minor crank length alteration would have no effect on exercise tolerance and power output.

Materials and methods

Participants

Fourteen amateur road cyclists (9 males and 5 females) voluntarily participated in this study (Table 1). Participants were required to have been regularly cycling for a minimum of 3 years and routinely completing a training volume of more than 3 h per week. At the time of testing, participants were required to be injury free and take part in their usual routine of training and/or racing. Ethical approval was granted by the local ethics committee, and all participants provided written informed consent (ETH2122-0721).

Experimental protocol

The repeated measures assessment protocol was performed in a one-day session. Participants arrived at the laboratory with their road bikes after a 48-h period with no hard training. Prior to testing, anthropometric characteristics and bikes were measured (Figure 1) by a Torke Cycling bike fit qualified experimenter. These measurements of crank length, saddle height, saddle setback, handlebar drop and handlebar reach (Ferrer-Roca et al., 2017) and the participants clipless pedals were then transferred to a cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, the Netherlands) that allowed crank length modifications. Wearing their own cycling shoes with preferred cleat positions, participants then completed a 10-min warm-up at a self-selected intensity. After this, the power output was controlled by the participant's perceived exertion. Riders were given 10 min to adjust their intensity and be confident that their Rating of Perceived

Table 1. Characteristics (mean ± SD) of the cyclists and their bicycles.

		Mean ± SD	Range
Cyclists	Age (years)	26 ± 7	19–44
	Body mass (kg)	71.1 ± 12.3	50.2–94.1
	Height (cm)	174.1 ± 9.4	155.6–194.3
	Cycling experience (years)	9.4 ± 5.3	3.0–20.0
	Training volume (hours/week)	8.4 ± 5.0	3.0–15.0
	RPE 14 Power (W)	199.1 ± 50.5	148.0–299.0
	RPE 14 Power (W/kg)	2.8 ± 0.6	2.2–4.1
	Preferred cadence (rpm)	83.8 ± 7.2	70.0–90.0
Bicycles	Saddle height (mm)	877 ± 62	780–970
	Saddle setback (mm)	68 ± 31	35–130
	Reach (mm)	540 ± 46	440–60
	Handlebar drop (mm)	75 ± 28	35–130
	Preferred crank length (mm)	170.7 ± 2.7	165.0–172.5

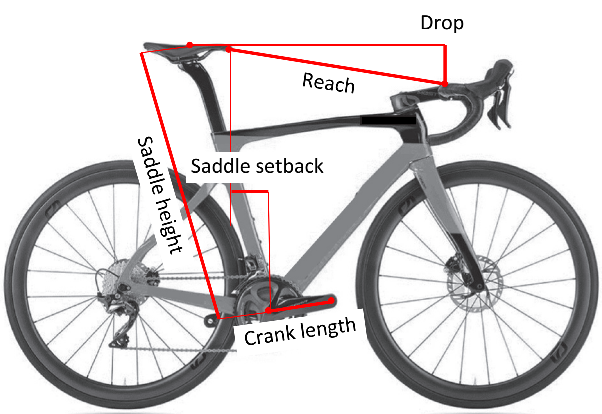

Figure 1. Bike measurements used to maintain consistent bike set-up.

Exertion (RPE) measured using the 6–20 scale (Borg, 1982) had reached 14 ('somewhat hard to hard'). To enable the average cadence at RPE 14 to be measured, participants were required to maintain this perceived effort for 3 min. This task also provided familiarisation with the intensity required during subsequent testing and with the prescription of intensity using RPE rather than power.

Using adjustable cranks (Adjustable sports cranks, Lode BV, Groningen, the Netherlands) on the Lode ergometer, five crank lengths were tested (preferred, 10 mm shorter, 5 mm shorter, 5 mm longer and 10 mm longer) in a randomised order. To isolate the effect of crank length, saddle and handlebar positions were adjusted after each crank length modification to comply with the bike measurements identified in Figure 1. With each crank length, participants then cycled for 5 min which included 1 min of familiarisation at RPE 11 ('fairly light') and 4 min at RPE 14. Longer familiarisation time was deemed unnecessary as participants regularly cycled using crank lengths within this standard range (Barratt et al., 2016). The RPE-based intensity prescription method (sometimes referred to as an 'RPE-Clamp') eliminated the necessity for baseline testing to establish workloads based on physiological thresholds, whilst ensuring consistent relative intensity among participants. RPE 14 was chosen as it is situated between the first (LT1) and second (LT2) lactate thresholds (Jamnick et al., 2020). This level of intensity is also sufficiently high to represent the demands of road cycling racing (Gallo et al., 2022) whilst minimising the impact of peripheral fatigue between trials (Thomas et al., 2016). Data were collected for 10 full pedal stroke revolutions in the final minute of the RPE 14 interval. Using live data provided by the Lode ergometer, participants were asked to maintain cadence for all crank lengths at the RPM determined at the end of the warm-up. During these intervals, riders were asked to remain seated with hands on the handlebar hoods.There was a 5-min rest period between each set to enable the crank length to be modified and the ergometer adjusted.

Kinematic analysis

Three-dimensional coordinate data were collected using a 12-camera Vicon motion capture system (Vicon Vantage V5, Vicon Motion Systems Ltd, Oxford, UK) sampling at 240 Hz. In accordance with Vicon's plug-in-gait lower body model, sixteen 14 mm retro-reflective markers were attached to specified anatomical landmarks (Vicon, n.d.). The plug-in gait biomechanical model is based on the Newington Hospital Helen Hayes gait model (Kadaba et al., 1990) and has previously been used to assess cycling kinematics (Holliday et al., 2023). Where possible, markers were attached directly to the skin. However, the heel and toe markers were attached directly to the participant's cycling shoes, and pelvis markers were attached to tight-fitting, non-reflective bib-shorts. Automatic marker tracking was completed using Vicon Nexus 2.10.1 (Vicon Motion Systems Ltd, Oxford, UK). Marker trajectory data were then filtered using a Woltring filter routine (Woltring, 1986) with a predicted mean square error (MSE) of 10 mm (FitzGibbon et al., 2016; Molloy et al., 2008).

Local coordinate systems were defined for lower body segments including the pelvis, upper legs, shanks and feet such that the x, y, and z axes were predominantly sagittal, frontal and longitudinal directions, respectively. Segment angles for the pelvis were calculated with respect to the laboratory coordinate system, with positive angles representing anterior tilt, right side up and right side forward. Joint angles (hip, knee and ankle) were calculated with respect to adjacent segments, with positive angles representing flexion (dorsiflexion for the ankle), abduction and internal rotation (supination for the ankle), respectively (Vicon, n.d.). Analysis of 3D kinematic data was performed using MATLAB (MATLAB R2021a, MathWorks, USA) and was undertaken on cyclists' right side assuming symmetry between left and right sides (Ferrer-Roca et al., 2017). Kinematic data were time normalised for each pedal revolution. The mean and standard deviation of this time normalised data were then calculated from 10 consecutive pedal revolutions for each of the 5 crank lengths. The start and end of each revolution were defined by the top dead centre pedal position, which was identified using the maximum vertical position of the marker placed over the 2nd metatarsal head.

Statistical analysis

The effect of crank length on power output was analysed in Statistical Package for Social Sciences (SPSS version 28, IBM, New York, USA). Data normality, homogeneity of variance and sphericity were assessed by a Shapiro-Wilk, Levene's test and Mauchly's Test of Sphericity, respectively. A one-way repeated measures ANOVA was then used to examine the effect of crank length on power output. Statistical parametric mapping (SPM) repeated measures ANOVAs were used to examine the effect of crank length on time normalised lower body kinematic variables (Pataky et al., 2013). SPM identified regions of the pedal revolution where significant differences in biomechanical waveforms occurred. In addition, significant main effects were followed by a post-hoc SPM paired t-test and calculations of Cohen's d effect sizes. A Bonferroni correction was considered, but due to the nature of this study and the desire to control the type II error rate, it was not applied (Feise, 2002; Perneger, 1998). All SPM analyses were performed using the open-source MATLAB code (SPM1d, v.MO.4.5, www.spm1d.org), with detailed descriptions of SPM theory and methods provided elsewhere (Pataky et al., 2013).

Results

Power and cadence

The preferred crank length selected by 57% of the riders ($n = 8$) was 172.5 mm. Six riders preferred shorter lengths with four selecting 170 mm cranks and two selecting 165 mm cranks. Average cadence at RPE 14 in the final 3 min of the warm-up was 83.8 ± 7.2 rpm. A one-way repeated measures ANOVA suggested that among crank lengths, participants pedalled at a consistent cadence during the RPE 14 intervals ($F(4,44) = 1.410$, $p = 0.248$) (Table 2). Furthermore, the crank length had no effect on the power output at RPE 14 ($F(4, 44) = 0.814$, $p = 0.523$). Regardless of crank length, the mean power output during repeated 4-min intervals was 199.1 ± 50.5 W (range 145–299 W) or 2.8 ± 0.6 W/kg (range 2.1–4.1 W/kg) (Table 2).

Pelvis kinematics

SPM repeated measures ANOVAs revealed significant main effects of crank length on pelvic anterior-posterior tilt, obliquity and rotation (Figure 2). Significant

Table 2. The effect of crank length on power output and cadence at RPE 14 intensity.

	Power (W)		Cadence (RPM)	
Crank Length	Mean ± SD	Range	Mean ± SD	Range
−10 mm	197.8 ± 50.0	137–294	83.5 ± 7.2	72–95
−5 mm	198.8 ± 49.5	135–285	84.9 ± 5.7	73–93
Preferred	202.3 ± 49.4	145–299	84.1 ± 7.2	70–95
+5 mm	201.8 ± 49.4	143–291	85.5 ± 6.4	72–96
10 mm	199.8 ± 50.7	137–297	83.6 ± 7.2	70–95

effects of crank length on anterior-posterior pelvic tilt were identified at the beginning (0–40%) and end (74–100%) of the pedalling cycle (Figure 2(a–1)). The post-hoc analysis indicated that there was a tendency for more anterior pelvic tilt to be evident with shorter cranks (Figure 2(a–2)). Significant differences in pelvis obliquity and pelvis rotation according to crank length were also identified at 60–68% and 55–68% of the pedalling cycle, respectively (Figure 2(b–1,c–1)). These main effects suggest that during the period of the pedalling cycle just after the crank passes the bottom dead centre, the right side of the pelvis was significantly lower and rotated further forwards when the longest, +10 mm crank length was being used.

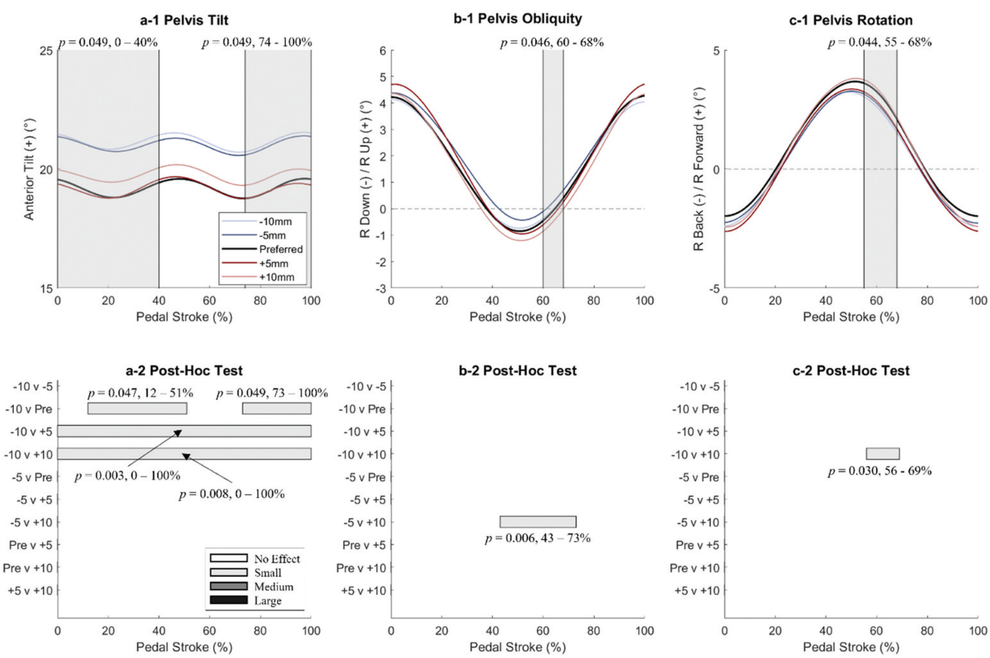

Figure 2. Changes in pelvis kinematics with crank length adjustment. 2(a1–c1) Represent joint angles and SPM results for the time series data and 2(a2–c2) represent results of the post-hoc test and effect sizes calculations.

Hip kinematics

SPM repeated measures ANOVAs revealed significant main effects of crank length on hip flexion and hip abduction but no effect on hip rotation (Figure 3). For hip flexion, a significant main effect of crank length was identified at the beginning of the pedalling cycle (0–13%) which indicated that significantly more hip flexion when the longest crank length was used (Figure 3(a)). For hip abduction, a significant difference according to crank length was identified at 29–76% of the pedalling cycle (Figure 3(b–1)) indicating that significantly more hip abduction was evident with the longest crank length (Figure 3(b–2)).

Knee kinematics

Significant effects of the crank length on knee flexion were identified at the beginning of the pedal stroke (0–24%) and for most of the upstroke (58–100%) (Figure 4(a–1)). The post-hoc analysis indicated that significantly more knee flexion was generally evident when the longer crank lengths were used (Figure 4(a–2)). Although there was no effect of crank length alteration on knee valgus or varus measurements during the pedalling cycle, a significant effect was identified on internal knee rotation during the upstroke (Figure 4 (c–1)). This indicated that more internal rotation was generally evident when longer cranks were used (Figure 4(c–2)).

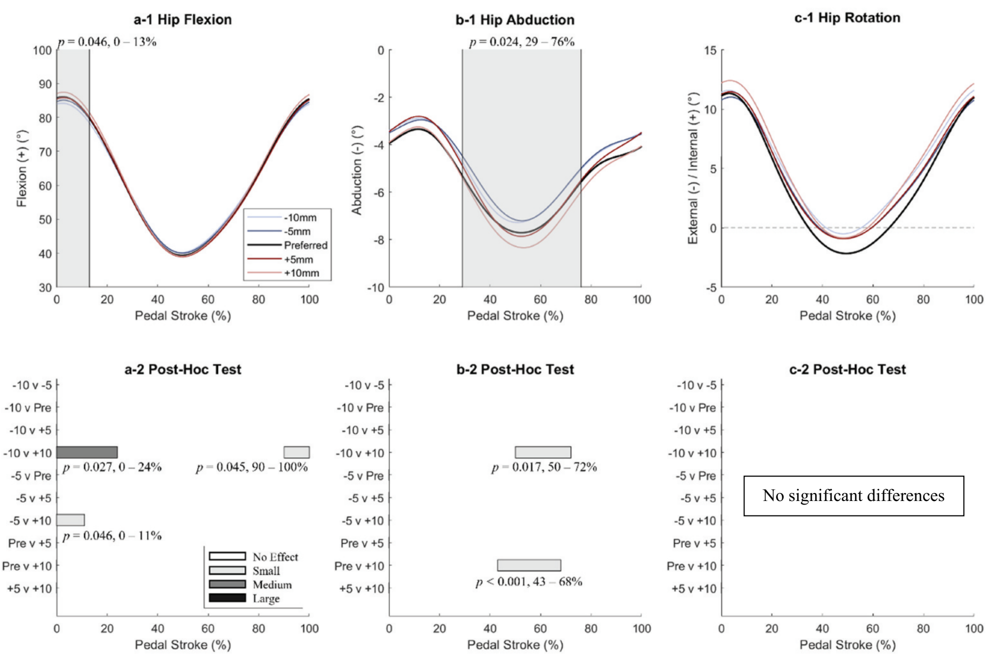

Figure 3. Changes in hip kinematics with crank length adjustment. 3(a1–c1) Represent joint angles and SPM results for the time series data and 3(a2–c2) represent results of the post-hoc test and effect sizes calculations.

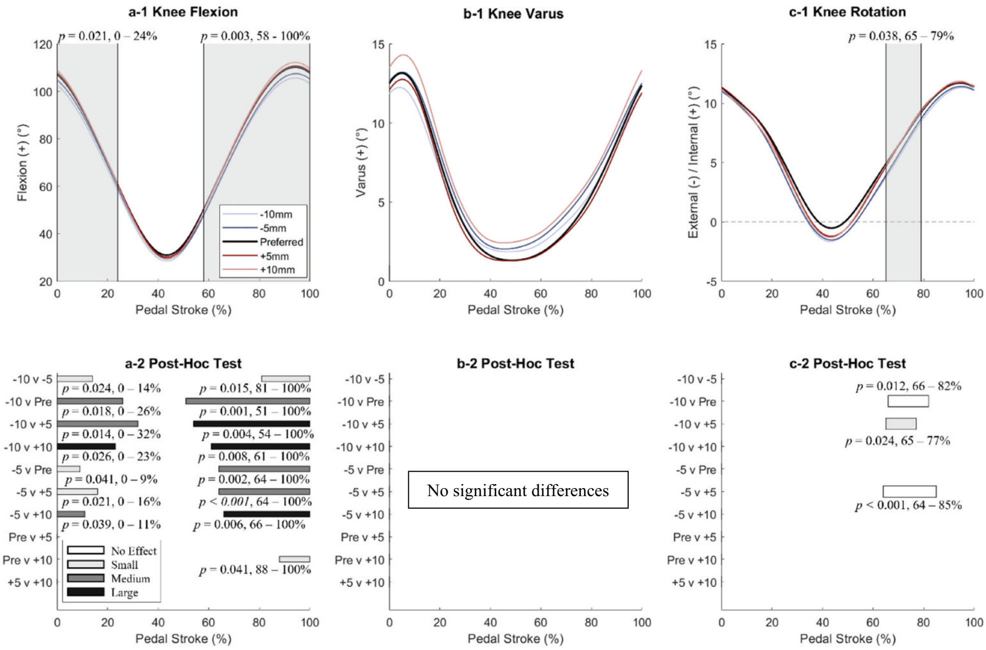

Figure 4. Changes in knee kinematics with crank length adjustment. 4(a1–c1) Represent joint angles and SPM results for the time series data and 4(a2–c2) represent results of the post-hoc test and effect sizes calculations.

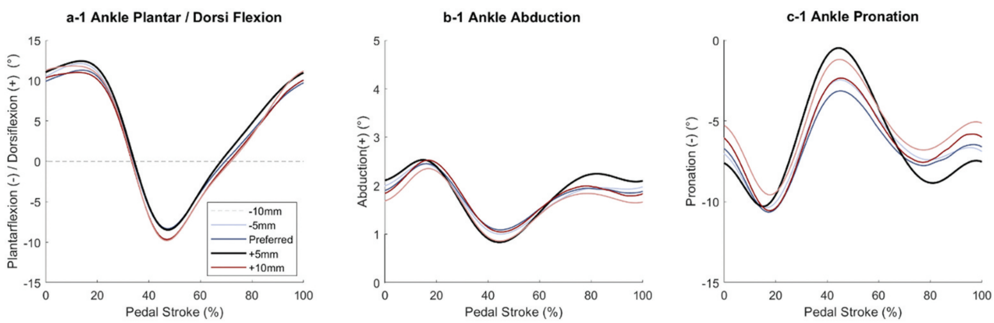

Figure 5. Changes in ankle kinematics with crank length adjustment. 6(a1–c1) Represent joint angles and SPM results for the time series data. No significant differences from post-hoc tests.

Ankle kinematics

The SPM repeated measures ANOVA indicated that there was no effect of crank length on sagittal, frontal or transverse plane ankle kinematics (Figure 5).

Discussion

This study examined the impact of minor crank length alterations on lower body cycling kinematics. Adjusting a rider's preferred crank length by commercially available increments of ±10 mm did not affect the mean power output during four-minute intervals performed at a sub-maximal but heavily perceived intensity. However, significant effects of crank length alterations were identified on the kinematics of the lower body. Shorter crank lengths were associated with more anterior pelvic tilt, less pelvic obliquity and rotation, decreased hip flexion and adduction and decreased knee flexion and internal rotation.

Exercise tolerance and power output

To examine the effect of crank length on exercise tolerance, we explored the relationship between subjective (RPE) and objective (power output) workloads. In all trials, cycling intensity was prescribed using an RPE clamp, with participants self-selecting their power output to maintain an RPE of 14. The similar mean power outputs produced across all crank lengths suggest that minor alterations (±10 mm) do not affect exercise tolerance (Table 2). This is consistent with findings observed over a similarly narrow range of crank lengths (Ferrer-Roca et al., 2017). Research examining a much wider range of crank lengths (145–195 mm) has also suggested that the energy cost (McDaniel et al., 2002) and lower body power production strategies (Barratt et al., 2016) of sub-maximal cycling remained stable. Therefore, our results contribute to the expanding body of evidence indicating that alterations in crank length do not significantly impact exercise tolerance and power output.

3D kinematics

Our results demonstrated that significantly more anterior pelvic tilt was displayed with the shortest −10 mm crank compared with the longer, preferred, +5 mm and +10 mm crank lengths (Figure 2(a)). The increased anterior pelvic tilt identified with the shortest crank could help to reduce injury risk and saddle discomfort. Increased anterior pelvic tilt can help a rider maintain a neutral lumbar curve, which has been suggested to reduce strain across the lower lumbar spine and reduce the risk of lower back pain (Muyor, Lopez-Minarro, et al., 2011). Increased anterior pelvic tilt can also help to distribute more body mass over the handlebars, thereby reducing or altering the load placed on the saddle (Bressel & Larson, 2002). Moreover, chafing, often attributed to pelvis movement and the repeated sliding of soft tissue across the saddle (Sauer et al., 2007), may be alleviated by shortening cranks. Excessive movement of the pelvis has traditionally been corrected by lowering a saddle (Sauer et al., 2007). However, the significant differences identified for pelvis obliquity and rotation in this study also suggest that pelvic motion could be reduced by shortening crank length (Figure 2). Although the statistical power of these findings may be limited, attempting to reduce pelvis motion through crank length adjustments could be considered as a final attempt during bike fitting if further reductions in saddle height would negatively impact the rider, for example, by increasing compressive forces on the patellofemoral joint (Bini et al., 2011). Crank length alterations could also be considered due to limiting factors of the cyclists such as poor hip range of motion.

Longer crank lengths were associated with increased hip and knee flexion during the start of the downstroke and end of the upstroke (Figures 3 and 4). These findings are consistent with previous research which reported that increases in hip and knee flexion were required to accommodate the increased distance between the feet when using longer cranks (Barratt et al., 2016; Ferrer-Roca et al., 2017; Park et al., 2022). However, changes in hip and knee flexion reported in this study were not just isolated to maximum flexion or top dead centre of the pedal stroke. Changes in hip flexion were identified for the first 13% of the downstroke (Figure 3(a)) whilst findings for the knee were identified more consistently throughout the pedal stroke (0–24% & 58–100%) (Figure 4(a)). In addition, the knee also appears to be more sensitive than the hip to minor changes in crank length. Significant differences in knee flexion were reported for most crank length combinations and, importantly, minor changes (±5 mm) from a rider's preferred choice caused significant differences in knee flexion (Figure 4(a–2)). This can have positive implications for riders, bike fitters and therapists as small changes in crank length could help riders prevent or recover from common overuse knee injuries. Lengthening cranks could help to minimise conditions such as patellofemoral pain syndrome (Bini et al., 2010) and anterior knee pain (Asplund & St Pierre, 2004; Gatti et al., 2021) whilst shortening cranks could help reduce the risk of posterior knee pain and iliotibial band syndrome (Farrell et al., 2003; Gatti et al., 2021).

The impact of crank length variation has previously focused on sagittal plane motion during cycling with only limited research examining frontal or transverse plane motion (Bini et al., 2016). Our results suggest that increasing crank length by 10 mm from a rider's preferred length can lead to greater hip abduction from mid-downstroke to mid-upstroke (29–76%) (Figure 3(b)). Increasing the crank length by 10 mm also produced greater internal knee rotation during the upstroke (Figure 4(c)). It has been suggested that increased non-sagittal plane motions such as this could potentially increase the risk of overuse knee injuries (Bini et al., 2016; Wang et al., 2020) particularly when combined with increased hip and knee flexion (Johnston et al., 2017). Therefore, these results provide further evidence that shorter cranks may be beneficial for those experiencing knee pain.

Alongside the potential reductions in injury risk associated with shorter cranks, the results suggest that shorter cranks may also enable riders to more easily achieve a lower handlebar position and subsequently facilitate a more aerodynamic position (Holliday & Swart, 2021; McEvoy et al., 2007). The increase in anterior pelvic tilt caused by shortening the cranks by as little as 10 mm could be particularly beneficial for male riders (Sauer et al., 2007) and older riders (Muyor, Alacid, et al., 2011) who because of reduced lumbar flexibility, tend to exhibit lower anterior pelvic tilt. The reduced hip and knee flexion identified with shorter cranks may also enable riders to more easily hold this position and could influence performance components. For example, less hip and knee flexion towards the top of the pedal stroke could help to eliminate thigh to torso contact which has the potential to comprise ventilation (Barratt et al., 2016).

Despite these crank length-related changes in pelvis, hip and knee joint kinematics, minor crank length changes did not alter ankle kinematics during the pedal stroke (Figure 5). This finding is consistent with previous research where longer crank lengths did not affect ankle joint excursion (Barratt et al., 2016; Ferrer-Roca et al., 2017; Park et al., 2022). It has been suggested that consistent ankle kinematics across different crank lengths are produced due to the requirement for the plantarflexes to stiffen the ankle joint during the downstroke to allow for efficient energy and force transfer to the pedals (Barratt et al., 2016; Holliday et al., 2023).

Limitations

The current study provided novel insights into the effects of crank length on lower body cycling kinematics. That said, this study did not account for alterations in seated saddle position that may have accompanied adjustments in crank length. The use of a saddle mapping device could provide further insight into how participants adjust their position among different crank lengths. Furthermore, cycling trials for each crank length were performed at a consistent pedalling cadence. This would have caused pedal speed to increase with longer cranks, which has the potential to influence lower body kinematics (Barratt et al., 2016). Finally, the use of subjective perception of effort to prescribe pedalling intensity could have influenced lower body kinematics. Although no differences in mean power output were observed between crank lengths, it is possible that large within-trial variability existed which could have influenced measured kinematics (Holliday et al., 2023).

Implications

It may be surmised that shortening a rider's preferred crank length by as little as 10 mm can provide numerous positive kinematic adaptations which could help to reduce the risk of cycling-related injuries and improve aerodynamic performance. As this has the potential to improve the overall cycling experience for riders of all abilities, major bike manufacturers should consider fitting shorter crank lengths as standard or offer crank length customisation during the buying process. As manufacturers currently prescribe crank length based on bike frame size, in case of doubt between two sizes, the one with shorter crank lengths might be recommended. Furthermore, our results suggest that bike fitters, clinicians and riders should consider crank length alteration as an effective bike manipulation. Shorter cranks may help a rider more easily achieve anterior pelvis rotation, reduce excessive hip and knee flexion around the top of the pedal stroke and limit non-sagittal plane motion.

Conclusion

This study revealed that commercially available alterations in crank length of ±10 mm had no effect on mean power output during four-minute intervals performed at a heavy intensity. However, shorter cranks may be particularly beneficial for cyclists suffering with overused hip and knee injuries as decreases in hip and knee flexion around the top of the pedal stroke and reduced non-sagittal plane motion were identified when shorter cranks were used. Shorter cranks also significantly increased anterior pelvic tilt, which has been associated with a reduced risk of lower back injury and improved aerodynamics.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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