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Descriptive profile for lower-limb range of motion in professional road cyclists

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ABSTRACT

BACKGROUND: To describe the lower limb range of motion (ROM) profile in professional road cyclists. **METHODS:** Cohort study. One hundred and twenty-one road cyclists volunteered to participate. ROM measurements of passive hip flexion, extension, internal rotation, external rotation, knee flexion and ankle dorsiflexion in dominant and non-dominant limbs were performed using an inclinometer. ROM scores were individually categorized as normal or restricted according to reference values. **RESULTS:** Overall, hip flexion was smaller in the non-dominant limb than in the dominant limb (F=12.429, p<0.001), with bilateral differences in male (95% Mean Diff=0.5º to 3.3º) and female cyclists (95% Mean Diff=0.1º to 3.1º). Sex differences were found in hip flexion (F=18.346, p<0.001), hip internal rotation (F=6.030, p=0.016) and ankle dorsiflexion (F=4.363, p=0.039), with males showing smaller ROM than females. Males and females had restricted knee flexion in dominant (males=51.6%; females=42.6%) and non-dominant limbs (males=45.0%; females=39.3%). Ankle dorsiflexion was also restricted in dominant (males=38.3%; females=31.1%) and non-dominant limbs (males=41.6%; females=34.4%). **CONCLUSIONS**: Elite road cyclists showed restricted lower-limb ROM according to reference values. In general, male cyclists showed lower values of ROM than females counterparts. These findings suggest that including specific stretching exercises and resistance training to improve knee and ankle dorsiflexion ROM may prevent muscle imbalances caused by chronic pedalling in professional cyclists.

Keywords: *Clinical examination; Injury prevention; Risk Factor; flexibility*

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Introduction

At the professional level, a male World Tour professional cyclist covers around 25,000 to 35,000 km each year and accumulates up to 100 competition days [1, 2]. During the course of this extreme workload, cyclists must adopt an unnatural body position, seated on a bicycle with a forced trunk anterior inclination and lumbar flexion [3]. As a consequence of this body position, chronic cycling may cause impairments the range of motion (ROM) of several body joints [4], which eventually could increase the risk of injuries.

Overuse injuries in cycling mostly occur during the training period, mainly in the lower-limb [5], particularly in the knee joint [6] and most injuries are catalogued as minor-moderate in terms of severity. External factors like the bicycle misalignment, and adverse road conditions may increase the risk of cycling injury [7]. However, a reduction in normal ROM in lower-limbs may also be a contributing risk factor for cycling injuries, although the evidence in cycling is lacking. To this regard, recent studies suggest that limited ankle dorsiflexion ROM predisposes for knee injuries such as patellar tendinopathy in basketball players [8] while restricted ankle dorsiflexion was 7-fold more common in individuals with patellofemoral pain than in control individuals [9]. This association can be explained by to the fact that a meaningful reduction of ankle dorsiflexion ROM restricts the ability to pass the leg forwards over the foot [10]. This anatomical alteration may lead to abnormal lower-limb biomechanics during closed-chain exercises [7] which could lead to pain and eventually cause an injury. However, to the authors' knowledge, no previous studies have examined ankle dorsiflexion ROM in cyclists and thus, there is no information to determine what ankle dorsiflexion ROM might be considered "normal" in cyclists.

In addition to lower-limb injuries, low back pain is one of the commonest complaints in cycling [7]. Previous studies suggested that sport-related body postures and repetitive movements during training and competition might influence neutral sagittal spinal curvatures [11]. Intervertebral stress, viscoelastic deformation of lumbar tissues, thoracic and lumbar intradiscal pressure and the development spinal disorders are among the main negative consequences of unnatural body postures associated to the characteristics of some sports such cycling [12]. In this regard, ROM deficits in hamstring muscle and prolonged periods of static trunk flexion have been suggested as predisposing factors for increasing the likelihood of lower back pain in non-athlete populations [13]. Furthermore, a lack of hip extension motion is compensated with an increase in anterior pelvic tilt, that might induce low back pain [14]. This compensation results in an abnormal mechanical load distribution in the hip that increases the activation of the low back musculature [15]. An excessive activation of lumbar spine extensor muscles may lead to early onset fatigue and decreased protection from the shearing and torsional loads to the lumbar spine. Core muscle activation imbalance and the flexed posture associated with cycling may lead to maladaptive spinal kinematics and increased overuse low back pain in cyclist [12]. However, despite hip motion is a critical factor in road cycling, the studies regarding hip flexion ROM in cyclists are scarce [3], with no previous studies examining the hip extension ROM in cycling.

Thus, the effect of chronic cycling may affect lower-limb ROM in professional cyclists, affecting the prevalence of chronic pain or injury. The aim of the present study was to describe the lower-limb ROM profile and identify sex-related differences in professional road cyclists.

Material and methods

Participants

Sixty male (mean ± SD; age: 22 ± 4 years) and sixty-one female (age: 21 ± 4 years), highly trained professional road cyclists participated in this study. Cyclists were recruited from a technical meeting organized by the Royal Spanish Cycling Federation which gather different cycling professional teams. The cyclists trained an average of 14.3 ± 5.3 h/w (males) and 14.9 ± 6.5 h/w (females) and had 10 ± 5 years of cycling experience. The participants' inclusion criteria were: (a) competing in a Union Cycliste Internationale (UCI) Word tour team; (b) being healthy and free of musculoskeletal injuries during the previous three months; (c) being involved in regular training and competition during the last season prior to the investigation; (d) no ingestion of painkillers nor other pain relieving medications for 72 h before testing. Before taking part in the study, participants and their parents/guardians were fully informed about the protocol and provided their written informed consent. This investigation was performed in accordance with the latest version of the Declaration of Helsinki and was approved by the Miguel Hernandez University of Elche Ethics Review Committee (code: DPC.VMP.01.18).

Data collection

Experimental testing was performed during the pre-season period of 2019 (November and December) by two experienced researchers (one conducted the testing and the other ensured proper testing position of the participants throughout the assessment manoeuvres). In each experimental session, participants performed a standardized warm-up which consisted of 5 min on a stationary exercise bike followed by 10 min of dynamic warm-up exercises (i.e., straight leg march, forward lunge with opposite arm reach, forward lunge with an elbow instep, lateral lunge, trunk rotations, multi-directional skipping) with increasing intensity. After the warm-up, the lower-limb ROM measurement protocol was explained to participants and demonstrated on each leg.

Measurements were performed in random order for both dominant and non-dominant limbs.

ROM measurement

Maximal ROM during passive hip flexion, extension, internal rotation and external rotation, and during knee flexion were measured using an inclinometer (ISOMED, USA) with a telescopic arm as previously described [16]. Each measurement was performed twice for each limb with a 30-s rest period between measurements and limbs. The highest ROM value for each measurement was used in the subsequent analysis. Unilateral ankle dorsiflexion ROM was assessed in each ankle using the Leg-Motion system test (LegMotion, Check your Motion, Spain). Three repetitions were performed in each limb with 10 s of passive recovery between trials. The best score (largest ROM) among these measurements was selected for subsequent analysis. ROM scores were individually categorized for each cyclist as normal or restricted, according to the reference cut-off values previously reported as clinically meaningful: hip flexion <80º [17], hip extension <0º [18], hip internal rotation <25º [19], hip external rotation <25º [20], knee flexion <114º [21] and ankle dorsiflexion <10 cm [17].

Statistical Analysis

Data are presented as means, standard deviation (SD) and 95% confidence intervals for the mean difference between limbs (95% CI Mean Diff). Outliers were identified by the ROUT method [22] and deleted for statistical analyses. Normality of the data was verified using the Kolmogorov-Smirnov test. A two-way analysis of variance (ANOVA) with one between-subjects factor (sex) and one within-subjects factor (limb) was conducted to analyse difference in each ROM variable. Effect size (ES) was estimated by Eta squared calculation [23] and it was categorized as small (0.01), medium (0.06) and large (0.14).

Statistical analyses were performed using the SPSS software version 20.0 (IBM Corp., Armonk, NY) and GraphPad Prism 6.01 (GraphPad Software Inc., California, USA).

Results

All the sixty male (height: 185.0 ± 0.4 cm, body mass: 71.1 ± 6.4 kg) and sixty-one female (height: 166.1 ± 7.4 cm, body mass: 61.2 ± 7.6 kg) professional road cyclists completed all the tests with no pain or discomfort. ANOVA yielded medium inter-limb differences in hip flexion (F=12.429, p<0.001, ES=0.10) with no other billateral differences in the remaining lower-limb ROM variables (F<2.828, p>0.09). Sex differences were found in hip flexion (F=18.346, p<0.001, ES=0.13), hip internal rotation (F=6.030, p=0.016, ES=0.05) and ankle dorsiflexion (F=4.363, p=0.039, ES=0.04), with males showing lower ROM values compared to females. No interaction effects (limb*sex) were identified (F>1.022, p>0.230). Table 1 shows the ROM values and limb differences for male and female elite cyclists. Results for each measurement are depicted in Figure 1. Hip flexion ROM in the non-dominant limb was smaller compared to the dominant (Figure 1.A) in both males (Mean difference = 1.9 ± 5.4º) and females (Mean difference = 1.6 ± 5.7º). Both male and female cyclists showed restricted ROM in hip flexion and extension (Figure 1.C and 1.D), and particularly in knee flexion (Figure 1.E) and ankle dorsiflexion (Figure 1.F). Sex-specific normative values for each ROM measurement are presented in Table 2.

Table 1. Mean comparison between range of motion (ROM) values for dominant and non-dominant limbs in male and female elite road cyclists.

Range of motion (ROM)	**Dominant limb**		**Non-dominant limb**		*Mean Diff 95% CI*
	Mean (SD)	*Restrict*[1]	*Mean (SD)*	*Restrict*[1]	
Male cyclists					
Hip flexion (°)	87.0 (9.5)[#$]	17%	85.1 (9.4)[#$]	17%	0.5; 3.3
Hip extension (°)	6.2 (8.8)	18%	5.8 (7.9)	18%	-0.8; 1.6
Hip IR (°)	53.7 (10.5)[$]	0%	52.3 (10.4)[$]	0%	-0.7; 3.5
Hip ER (°)	60.2 (6.1)	0%	59.8 (6.5)	0%	-1.6; 1.9
Knee flexion (°)	115.2 (16.6)	52%	115.9 (17.6)	45%	-3.0; 1.6
Ankle dorsiflexion (cm)	10.5 (3.5)[$]	38%	10.3 (3.5)[$]	42%	-0.4; 0.4
Female cyclists					
Hip flexion (°)	94.3 (11.2)[#$]	5%	92.7 (11.4)[#$]	7%	0.1; 3.1
Hip extension (°)	5.4 (9.8)	26%	5.7 (9.6)	23%	-1.6; 1.0
Hip IR (°)	57.7 (9.5)[$]	0%	56.7 (10.0)[$]	0%	-0.9; 2.9
Hip ER (°)	62.4 (5.4)	0%	62.5 (3.7)	0%	-1.6; 1.3
Knee flexion (°)	119.6 (18.1)	43%	118.9 (16.8)	39%	-1.0; 2.4
Ankle dorsiflexion (cm)	11.6 (3.0)[$]	31%	11.6 (3.2)[$]	34%	-0.2; 0.5

[1]Proportion of cyclists with restriction over cut-off values previously reported as clinically meaningful. IR: Internal rotation. ER: External rotation. #: Significant inter-limb differences; $: Significant between-sex differences.

******Insert Figure 1 here******

Table 2. Range of motion (ROM) normative data for professional male and female elite road cyclists

Range of motion (ROM)	**Dominant limb**			**Non-dominant limb**		
	25th	*75th*	*95% IC*	*25th*	*75th*	*95% IC*
Male cyclists						
Hip flexion (°)	80.0	91.8	84.5 - 89.4	80.0	90.0	82.7 - 87.5
Hip extension (°)	0.0	10.8	4.0 - 8.5	1.0	11.4	3.8 - 7.9
Hip IR (°)	44.8	60.0	45.0 - 56.5	44.3	60.0	49.7 - 55.0
Hip ER (°)	57.8	64.0	58.6 - 61.8	56.0	63.3	58.1 - 61.5
Knee flexion (°)	103.5	130.0	111 - 119.5	102.1	129.9	111.4 - 120.5
Ankle dorsiflexion (cm)	8.3	12.7	9.6 - 11.4	8.2	12.8	9.4 - 11.2
Female cyclists						
Hip flexion (°)	88.0	101.0	91.4 - 97.2	86.0	100.0	89.8 - 95.7
Hip extension (°)	-1.5	11.8	2.9 - 8.0	0.0	14.0	3.3 - 8.2
Hip IR (°)	51.0	63.5	55.2 - 60.1	49.0	63.5	54.2 - 59.3
Hip ER (°)	60.0	65.0	60.9 - 64.0	60.0	64.0	61.5 - 63.5
Knee flexion (°)	109.5	133.5	11.5 - 124.3	110.5	129.8	114.6 - 123.2
Ankle dorsiflexion (cm)	9.2	14.0	10.8 - 12.4	9.4	14.1	10.8 - 12.4

25th and 75th are percentiles (i.e., values below which the 25% and 75% of the observations may be found)

Discussion and implications

The main results of the current study were: i) as an average, male and female elite cyclists had smaller hip flexion ROM in the non-dominant limb compared to the dominant; ii) a considerable portion of male and female cyclists had restricted ROM compared to standard cut-off points for both dominant and non-dominant limbs in knee flexion (males > 45%; females > 39%), hip flexion (males = 17%; females > 5%) and extension (males = 18%; females > 23%) and ankle dorsiflexion (males = 38%; females > 31%); iii) sex-related differences were found in hip flexion, internal rotation and ankle dorsiflexion, with males showing smaller ROM values compared to females. To the authors' knowledge, this is the first study describing a full lower-body ROM profile in professional road cyclists. This information might be useful for coaches and physiographists because it presents reference values of lower-limb ROM in elite cyclists free from any cycling-related overuse injury. The obtaining of these simple ROM measurements is recommended in elite cyclist in order to detect cyclist with ROM deficits.

Overall, the current analysis indicates that both male and female elite road cyclists had between 1.7 and 2.2% reduced passive hip flexion ROM in the non-dominant limb compared to the dominant limb (Table 1). However, it must be noted that the ROM values obtained were quite similar to those reported in previous studies on cyclists [3], suggesting that this is a normal finding in cycling. Reduced hip flexion ROM might be the product of the biceps femoris hypertrophy and stiffness developed during chronic pedalling. Although from a kinematic and kinetic points of view pedalling can be considered as a symmetric movement, a number of studies observed unilateral differences in pedalling forces [23]. Specifically, changes in asymmetry with pedalling rate are highly subject-specific and unrelated to limb dominance. Hence, the existence partial hip flexion imbalance between dominant and non-dominant limbs seems to be a sport-specific adaptation to chronic cycling at professional levels. However, this is a speculation that merits further investigation, especially to understand the mechanism(s) that produce(s) this imbalance.

Around 40-50% of male and 30-40% of female professional cyclists presented a restricted knee flexion (<114º) and/or ankle dorsiflexion (<10 cm) in both dominant and non-dominant limbs compared to previous cut-off values. Again, these findings could be associated to the high pedalling workload at elite level [2] that induces significative muscle hypertrophy of hip extensor, knee extensor and ankle plantar muscles as primary contributors of power output during cycling [24]. Previous study reported that a loss of knee flexion and ankle dorsiflexion ROM predisposes for the most prevalent knee pathologies in athletes such as patellar tendinopathy and Achilles tendinopathy [25]. However, to date, there is no report indicating an association between injury ratings and restricted knee or ankle ROM in cycling, probably because the measurement of lower-limb ROM is an unusual assessment in cyclists. Reductions in ankle dorsiflexion may influence pedalling mechanics by limiting the ability to pass the leg forwards over the foot [26], which consequently could cause a greater stress on the knee. Based on the present results, preventive exercises to enhance the hip, knee, and ankle mobility seem to be recommended for professional road cyclists and should be integrated in their conditioning and injury prevention programmes. According to a recent review [27], resistance training appears to be the most effective method to increase the ROM and reduce the injury risks and thus, ROM normal levels might be obtained by exercise modalities that cause more robust physical conditioning benefits than stretching. Nevertheless, the efficacy of the increased hip, knee, and ankle mobility to reduce injury prevalence must be determined in prospective epidemiological investigations.

In addition to common ROM profiles, we observed particular sex-related differences in hip flexion, hip internal rotation and ankle dorsiflexion (Table 1), always favouring ROM values in women. As expected, males had lower joint laxity [28], which can be explained due to higher muscle stiffness [29], and gender differences in hormonal status [28] and the viscoelastic properties on the muscle [29]. For example, the hormone relaxin is associated with ligamentous relaxation, which is likely to be responsible for increased joint laxity in females [30]. Furthermore, a lower muscle cross-sectional area and intrinsically more compliant muscle in the females could explain the increase ROM [29]. The current data is a first step in determining sex-differences in lower-limbs ROM of professional road cyclists while the sport significance of this finding must be determined by comparing the ratings of injury in both populations of cyclists.

The major strength of this study is being the first report describing the full profile of lower-limb ROM in professional road cyclists. However, some limitations exist as to the interpretation of data. As the present study was performed in a specific sample of elite cyclist, the findings presented should not be extended to other athletes or to the general population. In addition, the analysis includes data for passive ROM tests during the pre-season period. Future studies should examine possible variations along the competitive season and determine the relationship between lower-limb ROM and injury risk or pedalling performance in professional cyclists. Finally, it is possible that some of the ROM differences found in this investigation are associated to the particular characteristics of training in each cyclist/team, particularly to the use of stretching and resistance exercise.

Conclusion

In summary, this study provides a full profile for lower-limb ROM (hip flexion, extension, internal and external rotation, knee flexion and ankle dorsiflexion) in professional road cyclists. Both males and females had reduced hip flexion in the non-dominant limb while a considerable proportion of cyclists presented restricted ROM values for knee flexion and ankle dorsiflexion in both limbs. As could be expected, females showed greater ROM values than male cyclists in several lower-limb joints. As a practical application, these findings may suggest the necessity of including specific stretching exercises and resistance training aimed at improving knee and ankle dorsiflexion ROM to prevent muscle imbalances caused by chronic pedalling.

Competing interest

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

Authors' contributions.

VM and MM conceived the research idea and collected the sample data. JC analyzed the data and statistically interpreted the findings. VM, JC and JDC prepared the manuscript and VM, JC, MM, AL and JC critically revised the article, read and approved the final manuscript.

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Tables and figure Legends:

Figure legends

Figure 1. Range of motion (ROM) for elite male (blue dots) and female cyclists (green dots) in dominant (dark coloured) and non-dominant limbs (light coloured). Dotted vertical lines are means, horizontal black lines are standard deviations. Red shaded area indicates restricted ROM according to standard cut-off points. Red circles are outliers. P values indicate significant differences between dominant and non-dominant limbs.

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ABSTRACT

BACKGROUND: To describe the lower limb range of motion (ROM) profile in professional road cyclists. **METHODS:** Cohort study. One hundred and twenty-one road cyclists volunteered to participate. ROM measurements of passive hip flexion, extension, internal rotation, external rotation, knee flexion and ankle dorsiflexion in dominant and non-dominant limbs were performed using an inclinometer. ROM scores were individually categorized as normal or restricted according to reference values. **RESULTS:** Overall, hip flexion was smaller in the non-dominant limb than in the dominant limb (F=12.429, p<0.001), with bilateral differences in male (95% Mean Diff=0.5º to 3.3º) and female cyclists (95% Mean Diff=0.1º to 3.1º). Sex differences were found in hip flexion (F=18.346, p<0.001), hip internal rotation (F=6.030, p=0.016) and ankle dorsiflexion (F=4.363, p=0.039), with males showing smaller ROM than females. Males and females had restricted knee flexion in dominant (males=51.6%; females=42.6%) and non-dominant limbs (males=45.0%; females=39.3%). Ankle dorsiflexion was also restricted in dominant (males=38.3%; females=31.1%) and non-dominant limbs (males=41.6%; females=34.4%). **CONCLUSIONS**: Elite road cyclists showed restricted lower-limb ROM according to reference values. In general, male cyclists showed lower values of ROM than females counterparts. These findings suggest that including specific stretching exercises and resistance training to improve knee and ankle dorsiflexion ROM may prevent muscle imbalances caused by chronic pedalling in professional cyclists.

Keywords**:** *Clinical examination; Injury prevention; Risk Factor; flexibility*

Word Count:2244

Introduction

At the professional level, a male World Tour professional cyclist covers around 25,000 to 35,000 km each year and accumulates up to 100 competition days [1, 2]. During the course of this extreme workload, cyclists must adopt an unnatural body position, seated on a bicycle with a forced trunk anterior inclination and lumbar flexion [3]. As a consequence of this body position, chronic cycling may cause impairments the range of motion (ROM) of several body joints [4], which eventually could increase the risk of injuries.

Overuse injuries in cycling mostly occur during the training period, mainly in the lower-limb [5], particularly in the knee joint [6] and most injuries are catalogued as minor-moderate in terms of severity. External factors like the bicycle misalignment, and adverse road conditions may increase the risk of cycling injury [7]. However, a reduction in normal ROM in lower-limbs may also be a contributing risk factor for cycling injuries, although the evidence in cycling is lacking. To this regard, recent studies suggest that limited ankle dorsiflexion ROM predisposes for knee injuries such as patellar tendinopathy in basketball players [8] while restricted ankle dorsiflexion was 7-fold more common in individuals with patellofemoral pain than in control individuals [9]. This association can be explained by to the fact that a meaningful reduction of ankle dorsiflexion ROM restricts the ability to pass the leg forwards over the foot [10]. This anatomical alteration may lead to abnormal lower-limb biomechanics during closed-chain exercises [7] which could lead to pain and eventually cause an injury. However, to the authors' knowledge, no previous studies have examined ankle dorsiflexion ROM in cyclists and thus, there is no information to determine what ankle dorsiflexion ROM might be considered "normal" in cyclists.

In addition to lower-limb injuries, low back pain is one of the commonest complaints in cycling [7]. Previous studies suggested that sport-related body postures and repetitive movements during training and competition might influence neutral sagittal spinal curvatures [11]. Intervertebral stress, viscoelastic deformation of lumbar tissues, thoracic and lumbar intradiscal pressure and the development spinal disorders are among the main negative consequences of unnatural body postures associated to the characteristics of some sports such cycling [12]. In this regard, ROM deficits in hamstring muscle and prolonged periods of static trunk flexion have been suggested as predisposing factors for increasing the likelihood of lower back pain in non-athlete populations [13]. Furthermore, a lack of hip extension motion is compensated with an increase in anterior pelvic tilt, that might induce low back pain [14]. This compensation results in an abnormal mechanical load distribution in the hip that increases the activation of the low back musculature [15]. An excessive activation of lumbar spine extensor muscles may lead to early onset fatigue and decreased protection from the shearing and torsional loads to the lumbar spine. Core muscle activation imbalance and the flexed posture associated with cycling may lead to maladaptive spinal kinematics and increased overuse low back pain in cyclist [12]. However, despite hip motion is a critical factor in road cycling, the studies regarding hip flexion ROM in cyclists are scarce [3], with no previous studies examining the hip extension ROM in cycling.

Thus, the effect of chronic cycling may affect lower-limb ROM in professional cyclists, affecting the prevalence of chronic pain or injury. The aim of the present study was to describe the lower-limb ROM profile and identify sex-related differences in professional road cyclists.

Material and methods

Participants

Sixty male (mean ± SD; age: 22 ± 4 years) and sixty-one female (age: 21 ± 4 years), highly trained professional road cyclists participated in this study. Cyclists were recruited from a technical meeting organized by the Royal Spanish Cycling Federation which gather different cycling professional teams. The cyclists trained an average of 14.3 ± 5.3 h/w (males) and 14.9 ± 6.5 h/w (females) and had 10 ± 5 years of cycling experience. The participants' inclusion criteria were: (a) competing in a Union Cycliste Internationale (UCI) Word tour team; (b) being healthy and free of musculoskeletal injuries during the previous three months; (c) being involved in regular training and competition during the last season prior to the investigation; (d) no ingestion of painkillers nor other pain relieving medications for 72 h before testing. Before taking part in the study, participants and their parents/guardians were fully informed about the protocol and provided their written informed consent. This investigation was performed in accordance with the latest version of the Declaration of Helsinki and was approved by the Miguel Hernandez University of Elche Ethics Review Committee (code: DPC.VMP.01.18).

Data collection

Experimental testing was performed during the pre-season period of 2019 (November and December) by two experienced researchers (one conducted the testing and the other ensured proper testing position of the participants throughout the assessment manoeuvres). In each experimental session, participants performed a standardized warm-up which consisted of 5 min on a stationary exercise bike followed by 10 min of dynamic warm-up exercises (i.e., straight leg march, forward lunge with opposite arm reach, forward lunge with an elbow instep, lateral lunge, trunk rotations, multi-directional skipping) with increasing intensity. After the warm-up, the lower-limb ROM measurement protocol was explained to participants and demonstrated on each leg.

Measurements were performed in random order for both dominant and non-dominant limbs.

ROM measurement

Maximal ROM during passive hip flexion, extension, internal rotation and external rotation, and during knee flexion were measured using an inclinometer (ISOMED, USA) with a telescopic arm as previously described [16]. Each measurement was performed twice for each limb with a 30-s rest period between measurements and limbs. The highest ROM value for each measurement was used in the subsequent analysis. Unilateral ankle dorsiflexion ROM was assessed in each ankle using the Leg-Motion system test (LegMotion, Check your Motion, Spain). Three repetitions were performed in each limb with 10 s of passive recovery between trials. The best score (largest ROM) among these measurements was selected for subsequent analysis. ROM scores were individually categorized for each cyclist as normal or restricted, according to the reference cut-off values previously reported as clinically meaningful: hip flexion <80º [17], hip extension <0º [18], hip internal rotation <25º [19], hip external rotation <25º [20], knee flexion <114º [21] and ankle dorsiflexion <10 cm [17].

Statistical Analysis

Data are presented as means, standard deviation (SD) and 95% confidence intervals for the mean difference between limbs (95% CI Mean Diff). Outliers were identified by the ROUT method [22] and deleted for statistical analyses. Normality of the data was verified using the Kolmogorov-Smirnov test. A two-way analysis of variance (ANOVA) with one between-subjects factor (sex) and one within-subjects factor (limb) was conducted to analyse difference in each ROM variable. Effect size (ES) was estimated by Eta squared calculation [23] and it was categorized as small (0.01), medium (0.06) and large (0.14).

Statistical analyses were performed using the SPSS software version 20.0 (IBM Corp., Armonk, NY) and GraphPad Prism 6.01 (GraphPad Software Inc., California, USA).

Results

All the sixty male (height: 185.0 ± 0.4 cm, body mass: 71.1 ± 6.4 kg) and sixty-one female (height: 166.1 ± 7.4 cm, body mass: 61.2 ± 7.6 kg) professional road cyclists completed all the tests with no pain or discomfort. ANOVA yielded medium inter-limb differences in hip flexion (F=12.429, p<0.001, ES=0.10) with no other billateral differences in the remaining lower-limb ROM variables (F<2.828, p>0.09). Sex differences were found in hip flexion (F=18.346, p<0.001, ES=0.13), hip internal rotation (F=6.030, p=0.016, ES=0.05) and ankle dorsiflexion (F=4.363, p=0.039, ES=0.04), with males showing lower ROM values compared to females. No interaction effects (limb*sex) were identified (F>1.022, p>0.230). Table 1 shows the ROM values and limb differences for male and female elite cyclists. Results for each measurement are depicted in Figure 1. Hip flexion ROM in the non-dominant limb was smaller compared to the dominant (Figure 1.A) in both males (Mean difference = 1.9 ± 5.4º) and females (Mean difference = 1.6 ± 5.7º). Both male and female cyclists showed restricted ROM in hip flexion and extension (Figure 1.C and 1.D), and particularly in knee flexion (Figure 1.E) and ankle dorsiflexion (Figure 1.F). Sex-specific normative values for each ROM measurement are presented in Table 2.

Table 1. Mean comparison between range of motion (ROM) values for dominant and non-dominant limbs in male and female elite road cyclists.

Range of motion (ROM)	Dominant limb		Non-dominant limb		Mean Diff 95% CI
	Mean (SD)	*Restrict*[1]	*Mean (SD)*	*Restrict*[1]	
Male cyclists					
Hip flexion (°)	87.0 (9.5)[#$]	17%	85.1 (9.4)[#$]	17%	0.5; 3.3
Hip extension (°)	6.2 (8.8)	18%	5.8 (7.9)	18%	-0.8; 1.6
Hip IR (°)	53.7 (10.5)[$]	0%	52.3 (10.4)[$]	0%	-0.7; 3.5
Hip ER (°)	60.2 (6.1)	0%	59.8 (6.5)	0%	-1.6; 1.9
Knee flexion (°)	115.2 (16.6)	52%	115.9 (17.6)	45%	-3.0; 1.6
Ankle dorsiflexion (cm)	10.5 (3.5)[$]	38%	10.3 (3.5)[$]	42%	-0.4; 0.4
Female cyclists					
Hip flexion (°)	94.3 (11.2)[#$]	5%	92.7 (11.4)[#$]	7%	0.1; 3.1
Hip extension (°)	5.4 (9.8)	26%	5.7 (9.6)	23%	-1.6; 1.0
Hip IR (°)	57.7 (9.5)[$]	0%	56.7 (10.0)[$]	0%	-0.9; 2.9
Hip ER (°)	62.4 (5.4)	0%	62.5 (3.7)	0%	-1.6; 1.3
Knee flexion (°)	119.6 (18.1)	43%	118.9 (16.8)	39%	-1.0; 2.4
Ankle dorsiflexion (cm)	11.6 (3.0)[$]	31%	11.6 (3.2)[$]	34%	-0.2; 0.5

[1]Proportion of cyclists with restriction over cut-off values previously reported as clinically meaningful. IR: Internal rotation. ER: External rotation. #: Significant inter-limb differences; $: Significant between-sex differences.

Insert Figure 1 here

Table 2. Range of motion (ROM) normative data for professional male and female elite road cyclists

Range of motion (ROM)	Dominant limb			Non-dominant limb		
	25th	*75th*	*95% IC*	*25th*	*75th*	*95% IC*
Male cyclists						
Hip flexion (°)	80.0	91.8	84.5 - 89.4	80.0	90.0	82.7 - 87.5
Hip extension (°)	0.0	10.8	4.0 - 8.5	1.0	11.4	3.8 - 7.9
Hip IR (°)	44.8	60.0	45.0 - 56.5	44.3	60.0	49.7 - 55.0
Hip ER (°)	57.8	64.0	58.6 - 61.8	56.0	63.3	58.1 - 61.5
Knee flexion (°)	103.5	130.0	111 - 119.5	102.1	129.9	111.4 - 120.5
Ankle dorsiflexion (cm)	8.3	12.7	9.6 - 11.4	8.2	12.8	9.4 - 11.2
Female cyclists						
Hip flexion (°)	88.0	101.0	91.4 - 97.2	86.0	100.0	89.8 - 95.7
Hip extension (°)	-1.5	11.8	2.9 - 8.0	0.0	14.0	3.3 - 8.2
Hip IR (°)	51.0	63.5	55.2 - 60.1	49.0	63.5	54.2 - 59.3
Hip ER (°)	60.0	65.0	60.9 - 64.0	60.0	64.0	61.5 - 63.5
Knee flexion (°)	109.5	133.5	11.5 - 124.3	110.5	129.8	114.6 - 123.2
Ankle dorsiflexion (cm)	9.2	14.0	10.8 - 12.4	9.4	14.1	10.8 - 12.4

25th and 75th are percentiles (i.e., values below which the 25% and 75% of the observations may be found)

Discussion and implications

The main results of the current study were: i) as an average, male and female elite cyclists had smaller hip flexion ROM in the non-dominant limb compared to the dominant; ii) a considerable portion of male and female cyclists had restricted ROM compared to standard cut-off points for both dominant and non-dominant limbs in knee flexion (males > 45%; females > 39%), hip flexion (males = 17%; females > 5%) and extension (males = 18%; females > 23%) and ankle dorsiflexion (males = 38%; females > 31%); iii) sex-related differences were found in hip flexion, internal rotation and ankle dorsiflexion, with males showing smaller ROM values compared to females. To the authors' knowledge, this is the first study describing a full lower-body ROM profile in professional road cyclists. This information might be useful for coaches and physiographists because it presents reference values of lower-limb ROM in elite cyclists free from any cycling-related overuse injury. The obtaining of these simple ROM measurements is recommended in elite cyclist in order to detect cyclist with ROM deficits.

Overall, the current analysis indicates that both male and female elite road cyclists had between 1.7 and 2.2% reduced passive hip flexion ROM in the non-dominant limb compared to the dominant limb (Table 1). However, it must be noted that the ROM values obtained were quite similar to those reported in previous studies on cyclists [3], suggesting that this is a normal finding in cycling. Reduced hip flexion ROM might be the product of the biceps femoris hypertrophy and stiffness developed during chronic pedalling. Although from a kinematic and kinetic points of view pedalling can be considered as a symmetric movement, a number of studies observed unilateral differences in pedalling forces [23]. Specifically, changes in asymmetry with pedalling rate are highly subject-specific and unrelated to limb dominance. Hence, the existence partial hip flexion imbalance between dominant and non-dominant limbs seems to be a sport-specific adaptation to chronic cycling at professional levels. However, this is a speculation that merits further investigation, especially to understand the mechanism(s) that produce(s) this imbalance.

Around 40-50% of male and 30-40% of female professional cyclists presented a restricted knee flexion (<114º) and/or ankle dorsiflexion (<10 cm) in both dominant and non-dominant limbs compared to previous cut-off values. Again, these findings could be associated to the high pedalling workload at elite level [2] that induces significative muscle hypertrophy of hip extensor, knee extensor and ankle plantar muscles as primary contributors of power output during cycling [24]. Previous study reported that a loss of knee flexion and ankle dorsiflexion ROM predisposes for the most prevalent knee pathologies in athletes such as patellar tendinopathy and Achilles tendinopathy [25]. However, to date, there is no report indicating an association between injury ratings and restricted knee or ankle ROM in cycling, probably because the measurement of lower-limb ROM is an unusual assessment in cyclists. Reductions in ankle dorsiflexion may influence pedalling mechanics by limiting the ability to pass the leg forwards over the foot [26], which consequently could cause a greater stress on the knee. Based on the present results, preventive exercises to enhance the hip, knee, and ankle mobility seem to be recommended for professional road cyclists and should be integrated in their conditioning and injury prevention programmes. According to a recent review [27], resistance training appears to be the most effective method to increase the ROM and reduce the injury risks and thus, ROM normal levels might be obtained by exercise modalities that cause more robust physical conditioning benefits than stretching. Nevertheless, the efficacy of the increased hip, knee, and ankle mobility to reduce injury prevalence must be determined in prospective epidemiological investigations.

In addition to common ROM profiles, we observed particular sex-related differences in hip flexion, hip internal rotation and ankle dorsiflexion (Table 1), always favouring ROM values in women. As expected, males had lower joint laxity [28], which can be explained due to higher muscle stiffness [29], and gender differences in hormonal status [28] and the viscoelastic properties on the muscle [29]. For example, the hormone relaxin is associated with ligamentous relaxation, which is likely to be responsible for increased joint laxity in females [30]. Furthermore, a lower muscle cross-sectional area and intrinsically more compliant muscle in the females could explain the increase ROM [29]. The current data is a first step in determining sex-differences in lower-limbs ROM of professional road cyclists while the sport significance of this finding must be determined by comparing the ratings of injury in both populations of cyclists.

The major strength of this study is being the first report describing the full profile of lower-limb ROM in professional road cyclists. However, some limitations exist as to the interpretation of data. As the present study was performed in a specific sample of elite cyclist, the findings presented should not be extended to other athletes or to the general population. In addition, the analysis includes data for passive ROM tests during the pre-season period. Future studies should examine possible variations along the competitive season and determine the relationship between lower-limb ROM and injury risk or pedalling performance in professional cyclists. Finally, it is possible that some of the ROM differences found in this investigation are associated to the particular characteristics of training in each cyclist/team, particularly to the use of stretching and resistance exercise.

Conclusion

In summary, this study provides a full profile for lower-limb ROM (hip flexion, extension, internal and external rotation, knee flexion and ankle dorsiflexion) in professional road cyclists. Both males and females had reduced hip flexion in the non-dominant limb while a considerable proportion of cyclists presented restricted ROM values for knee flexion and ankle dorsiflexion in both limbs. As could be expected, females showed greater ROM values than male cyclists in several lower-limb joints. As a practical application, these findings may suggest the necessity of including specific stretching exercises and resistance training aimed at improving knee and ankle dorsiflexion ROM to prevent muscle imbalances caused by chronic pedalling.

Competing interest

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

Authors' contributions.

VM and MM conceived the research idea and collected the sample data. JC analyzed the data and statistically interpreted the findings. VM, JC and JDC prepared the manuscript and VM, JC, MM, AL and JC critically revised the article, read and approved the final manuscript.

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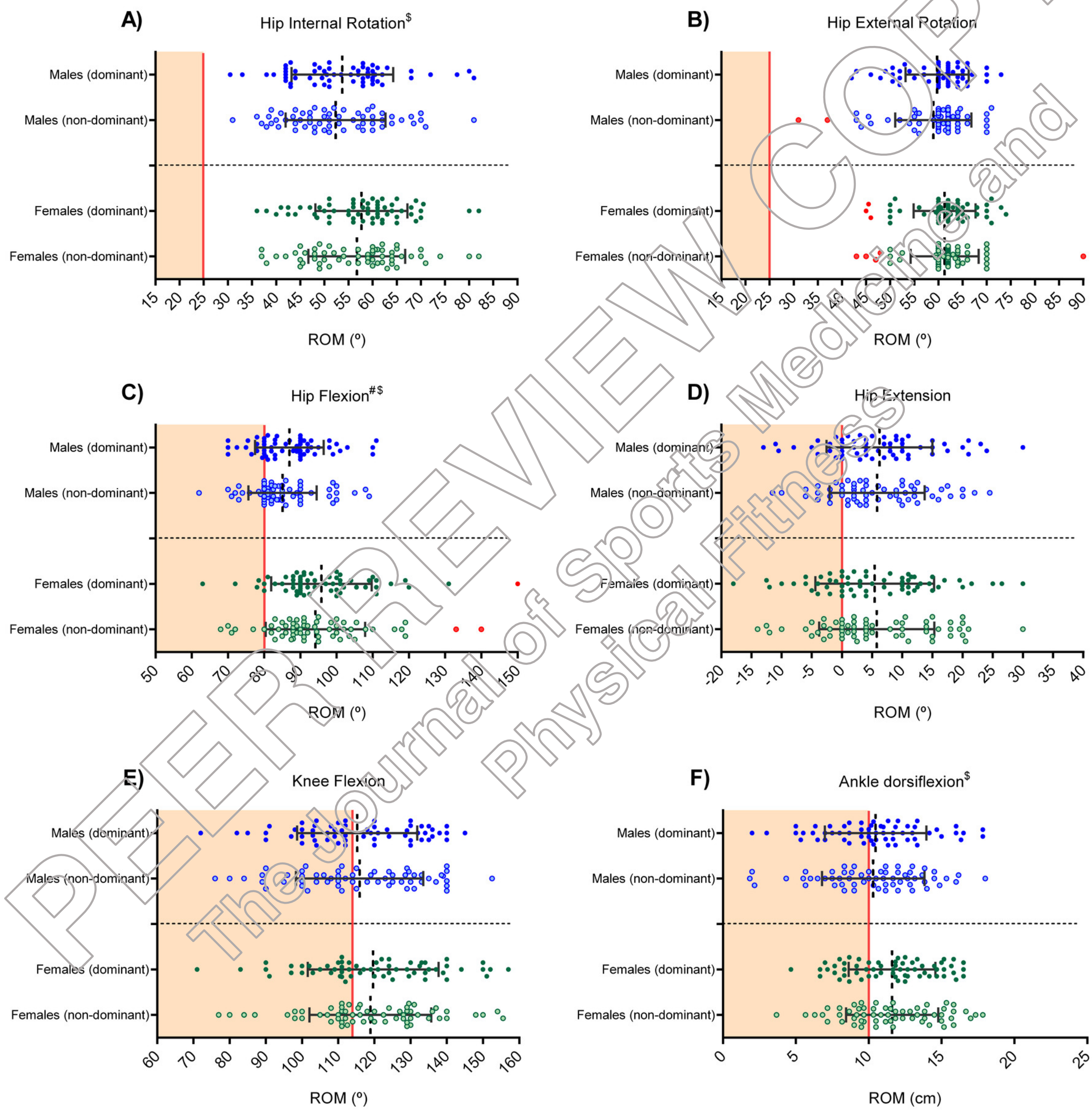
Tables and figure Legends:

Figure legends

Figure 1. Range of motion (ROM) for elite male (blue dots) and female cyclists (green dots) in dominant (dark coloured) and non-dominant limbs (light coloured). Dotted vertical lines are means, horizontal black lines are standard deviations. Red shaded area indicates restricted ROM according to standard cut-off points. Red circles are outliers. P values indicate significant differences between dominant and non-dominant limbs.



A)
Hip Internal Rotation$
B)
Hip External Rotation
C)
Hip Flexion#$
D)
Hip Extension
E)
Knee Flexion
F)
Ankle dorsiflexion$
Males (dominant)
Males (non-dominant)
Females (dominant)
Females (non-dominant)
ROM (°)
ROM (cm)