symmetry

MDPI

Article

Contralateral Asymmetry in Cycling Power Is Reproducible and Independent of Exercise Intensity at Submaximal Power Outputs

John W. Farrell III * and Valerie E. Neira

Clinical Biomechanics and Exercise Physiology Laboratory, Department of Health and Human Performance, Texas State University, San Marcos, TX 78666, USA; valerie_neira1@baylor.edu
* Correspondence: jwf77@txstate.edu

Abstract: The purpose of the current investigation was to examine the effects of exercise intensity on asymmetry in pedal forces when the accumulation of fatigue is controlled for, and to assess the reliability of asymmetry outcomes during cycling. Participants completed an incremental cycling test to determine maximal oxygen consumption and the power that elicited maximal oxygen consumption (pVO_2max). Participants were allotted 30 min of recovery before then cycling at 60%, 70%, 80%, and 90% of pVO_2max for 3 min each, with 5 min of active recovery between each intensity. Participants returned to the laboratory on separate days to repeat all measures. A two-way repeated measures analysis of variance (ANOVA) was utilized to detect differences in power production AI at each of the submaximal exercise intensities and between Trials 1 and 2. Intraclass correlations were utilized to assess the test–retest reliability for the power production asymmetry index (AI). An ANOVA revealed no significant intensity–visit interactions for the power production AI ($f = 0.835$, $p = 0.485$, $\eta^2 = 0.077$), with no significant main effects present. ICC indicated excellent reliability in the power production AI at all intensities. Exercise intensity did not appear to affect asymmetry in pedal forces, while excellent reliability was observed in asymmetry outcomes.

Keywords: asymmetry; cycling; pedaling; pedal forces; power

Citation: Farrell, J.W., III; Neira, V.E. Contralateral Asymmetry in Cycling Power Is Reproducible and Independent of Exercise Intensity at Submaximal Power Outputs. *Symmetry* **2023**, *15*, 1142. https://doi.org/10.3390/sym15061142

Academic Editor: John H. Graham

Received: 7 April 2023
Revised: 3 May 2023
Accepted: 18 May 2023
Published: 24 May 2023

1. Introduction

Asymmetry (i.e., significant differences between contralateral limbs) in physiological fitness components and contribution during bipedal movements has gained interest and has been widely investigated [1,2]. It has been noted that significant asymmetry for force production capabilities between the lower limbs has been associated with decrements in physical performance. Specifically, asymmetry in the force production of the lower limbs has been associated with reduced jump height and slower change of direction speed times [3,4]. Additionally, a strong focus has been placed on injury risk and occurrence in association with asymmetry [5]. Asymmetries > 15% have been associated with increased injury incidence in both athletic and non-athletic populations [5–8]. These results suggests that a reduction in asymmetry would be beneficial for enhancing performance and reducing injury risk.

Success in the sport of cycling is highly dependent upon the ability to generate and maintain sustained power outputs [9]. Thus, pedaling in a manner that maximizes the transfer of force into power production is of vital importance to cyclists. Asymmetry in force, torque, and power production have all been reported during cycling, with varying degrees of asymmetry reported [2,10–12]. Exercise intensity has been identified as a factor that influences the manifestation of asymmetry during cycling [11,13]. However, previous protocols have not accounted for the accumulation of fatigue during continuous incremental cycling tests or time trials. Previous investigations have reported significant increases in asymmetries in counter-movement jumps following repeated sprints, or during soccer matches [14,15]. It is unclear what degree of asymmetry will be present during cycling when the accumulation of fatigue is controlled for. Another key limitation in asymmetry research in general is a lack of reporting on the reliability of asymmetry outcomes [1]. This likely results in an assumption of the reliability of the asymmetry outcome, and an inability to determine the true degree of asymmetry [1,16].

Thus, the purpose of the current investigation was (1) to evaluate the effects of exercise intensity on pedal force asymmetries during bouts of submaximal cycling separated by periods of recovery to counteract the potential influence of the accumulation of fatigue, and (2) to determine the test–retest reliability of pedal force asymmetries. Submaximal exercise intensities were chosen for investigation to reflect the reported intensities within which cyclist accumulate the most time during races (~83% of total race time below VT_2/LT_2) [17]. Based on a previous investigation, it was hypothesized that pedal force asymmetries would not be statistically significantly different at different exercise intensities, and good-to-excellent test–retest reliability would be observed for pedal force asymmetries [12].

2. Materials and Methods

All participants completed two separate laboratory visits separated by at least 48 h but no more than one week. Visit 1 consisted of anthropometric measures, and an incremental cycling test (ICT) to determine the maximal oxygen consumption (VO_2max) and the power which elicited VO_2max (pVO_2max). Both VO_2max and pVO_2max were confirmed with a square wave bout verification protocol following the ICT. Participants then completed 4–3 min bouts of submaximal cycling at 60%, 70%, 80%, and 90% of pVO_2max in a randomized order, with 5 min of recovery between each bout. Asymmetry in pedal forces was assessed during each of the 3 min bouts of submaximal cycling. All procedures were repeated upon Visit 2 to assess the reliability of the pedal force asymmetry measures.

2.1. Participants

Eleven subjects (nine males and two females) were recruited for this investigation, all with $\geq$2 years of experience in cycling training and racing. Those with a previous history of lower limb orthopedic injuries or procedures (e.g., arthritis, hip replacement, or knee surgery) that could influence asymmetry outcomes were excluded. This study was approved by the Texas State University institutional review board, and each subject gave verbal and written informed consent prior to participation, in accordance with the Code of Ethics of the World Medical Association (the Declaration of Helsinki). All testing was conducted in a climate-controlled laboratory at a temperature of 20 to 22 °C.

2.2. Methodology

Subjects were instructed to abstain from eating, caffeine ingestion, and exercise two hours, 12 h, and 24 h, respectively, prior to each visit. A magnetically braked cycle ergometer (Sport Excalibur, Lode; B.V. Medical Technology, Croningen, The Netherlands) with built-in modified strain gauges within each crank arm was used for both ICTs and all bouts of submaximal cycling. The height and fore/aft positions of the seat and handlebars of the cycle ergometer were adjusted to each subject's comfort, and were recorded for replication on subsequent visits. The self-reported physical activity rating (PA-R) scale was used to determine initial workload of the ICT and subsequent increases in workload [18,19]. Briefly, PA-R is a 16 point scale describing levels of physical activity over the previous 6 months, with 0 being "avoid walking or exertion" and 15 being "run 50 miles or more per week or spend 13 h or more per week in comparable physical activity" [18,19]. PA-R, age, body mass index (BMI), and sex were plugged into an equation to estimate VO_2max and peak power output (PPO), with PPO then divided by the desired number of stages for the ICT [19]. The current ICT used one-minute stages, with workloads designed to induce task failure within 10 stages. Task failure was defined as a >10 revolution per minute (rpm) decrease from preferred cadence for >5 s despite strong verbal encouragement. PPO was determined using the following equation [20]:

$$\text{PPO} = \text{Wcom} + (\text{t}/60 \times \text{WLI})$$

where Wcom is the workload, in watts (W), for the final fully completed stage; *t* is the time, in seconds, that the final uncompleted stage was sustained; 60 is the duration, in seconds, for each stage; and WLI is the workload increment in W.

A square wave bout verification protocol was used to verify VO_2max and determine the power that elicited VO_2max (pVO_2max) [21]. Immediately upon reaching task failure for the ICT, participants began 3 min of active recovery at 50 watts (W), and then proceeded to cycle at their preferred cadence at 105% of PPO until reaching task failure again. Inspired and expired gases were collected and analyzed via a metabolic cart (True One 2400; Parvo Medics, Sandy, UT, USA) throughout the ICT and square wave bout verification to determine VO_2max. Gases were collected breath-by-breath and analyzed via 20 s averages. The highest 20 s average from either the ICT or square wave bout verification was defined as VO_2max, with the associated workload identified as pVO_2max.

Subjects were allotted 30 min of rest after completing the ICT and square wave bout verification. During this time, subjects were allowed to drink water ad libitum. Subjects then began cycling for 5 min at 50 W, serving as their warm-up. Subjects then completed 4–3 min bouts of cycling at 60%, 70%, 80%, and 90% of pVO_2max in a randomized order, separated by 5 min of active recovery at 50 W. Subjects were blinded to the workload and were instructed to maintain the same preferred cadence from the ICT throughout the submaximal bouts of cycling.

Methods for assessing pedal force asymmetries have been described previously [12]. Briefly, the independent modified stain gauges within each crank arm were calibrated prior to each use, so that strain gauges detected no forces while unloaded. Pedal force data were collected and analyzed using Lode Ergometry Manager (version 10. Lode: B.V. Medical Technology, Croningen, The Netherlands), with the amount of power generated during the crank cycle that resulted in forward propulsion reported as power in watts (W). Forces were collected independently for each lower limb and denoted as preferred (**PL**) or non-preferred limb (**NPL**) based on subjects response to the validated question "If you were to shoot a ball at a target, which leg would you use to kick the ball?", with the subjects' response recorded as their **PL** [8]. It has been recommended to use the terminology "preferred" rather than "dominant" when referring to a subjectively preferred limb for completing a task [22]. An asymmetry index (**AI**) was calculated for power production using the following equation:

$$\mathbf{AI}\ (\%) = \left[\frac{\mathbf{PL} - \mathbf{NPL}}{(\mathbf{PL} + \mathbf{NPL})/\mathbf{2}}\right] \times \mathbf{100}$$

AI values of -100 and 100 indicate 100% contribution from the **NPL** and **PL**, respectively. An **AI** of zero indicates equal contribution of both limbs [10,12]. A threshold of $\pm$10% for **AI** has previously been used to establish the presence of asymmetry for pedal forces during cycling [10,12].

2.3. Statistical Analysis

All analysis was conducted using IBM SPSS Statistics (version 26.0; IBM Corp., Armonk, NY, USA). Demographic data were summarized with descriptive statistics. Paired sample t-tests were used to assess significant difference in VO_2max and pVO_2max between Visits 1 and 2. Intraclass correlation coefficients (ICCs) were utilized to assess the test–retest reliability for the power production AI. ICCs were interpreted as having poor, good, and excellent reliability with coefficients of <0.4, 0.4 to 0.75, and >0.75, respectively [1,23]. Absolute reliability was evaluated using the coefficient of variation (CV) and the standard error of the measurement (SEM). A two-way repeated measures analysis of variance (ANOVA) was utilized to detect differences in the power production AI at each of the submaximal exercise intensities, and between Visits 1 and 2. Post hoc analysis was performed when appropriate, to identify significant differences. Effects sizes for the ANOVA were analyzed when appropriate using eta squared (n^2), with values of 0.02, 0.13, and 0.26 indicative of small, medium, and large effect sizes, respectively [24].

3. Results

The subjects' age, height and body mass (mean ± standard deviation) were observed to be 35.1 ± 16.5 years, 174.9 ± 7.0 cms, and 72.5 ± 15.9 kgs, respectively. Paired sample *t*-tests revealed no statistically significant differences in VO_2max (53.3 ± 12.0 mL/kg/min vs. 52.2 ± 12.2 mL/kg/min) and pVO_2max (349.5 ± 105.4 W vs. 341.0 ± 101.8 W) between Visits 1 and 2. Only 10 of the 11 participants' data were able to be used to determine VO_2max due to one participant experiencing feelings of claustrophobia while wearing the mask used to collect inspired and expired gases during the ICT. Two, four, three, and one participants were classified as performance level 1, 2, 3, and 4, respectively, according to Pauw et al.'s guidelines on using the metric of relative maximal oxygen consumption (VO_2max) assessed during the investigation [25].

Power production AI results and reliability data are reported in Table 1. Power production AI data were normally distributed. Individual asymmetry index values are illustrated in Figure 1. ICC results were interpreted as having excellent reliability in the power production AI at 60%, 70%, 80%, and 90% of pVO_2max. The two-way repeated measures ANOVA revealed no significant intensity–visit interactions for the power production AI ($f = 0.835$, $p = 0.485$, $\eta^2 = 0.077$), with no significant main effects present for intensity ($f = 0.270$, $p = 0.847$, $\eta^2 = 0.026$) or Visit ($f = 0.011$, $p = 0.919$, $\eta^2 = 0.001$).

Table 1. Asymmetry Index Results and Reliability (n = 11).

Variable	Visit 1 (Mean ± SD)	Visit 2 (Mean ± SD)	ICC r (95% CI)	*p*	CV	SEM
60% pVO_2max AI (%)	0.4 ± 13.4	1.3 ± 11.4	0.945 (0.797–0.985)	0.00	612.9	1.9
70% pVO_2max AI (%)	1.3 ± 15.6	−0.8 ± 10.3	0.792 (0.223–0.944)	0.01	594.0	4.8
80% pVO_2max AI (%)	1.9 ± 13.8	1.6 ± 9.4	0.777 (0.118–0.941)	0.02	4267.5	5.46
90% pVO_2max AI (%)	0.1 ± 8.8	2.5 ± 8.3	0.888 (0.604–0.969)	0.00	1404.5	5.51

Abbreviations: pVO_2max = power which elicited maximal oxygen consumption, AI = asymmetry index, SD = standard deviation, ICC = intraclass correlation coefficient, CI = confidence interval; CV = coefficient of variation; SEM = standard error of the measurement.

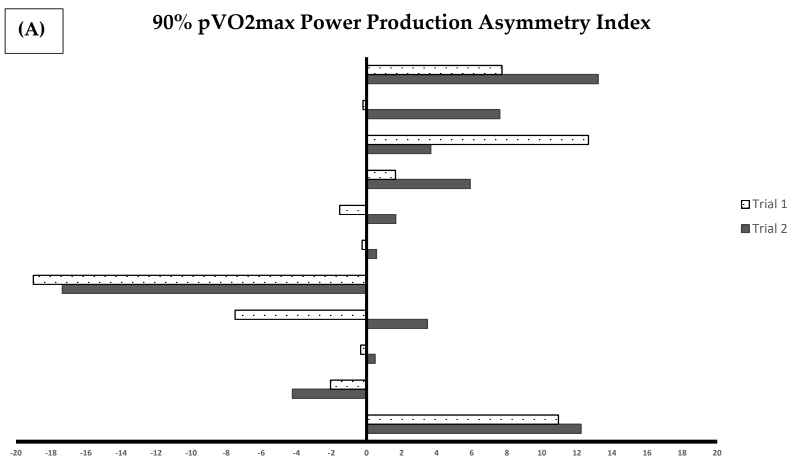

Figure 1. *Cont.*

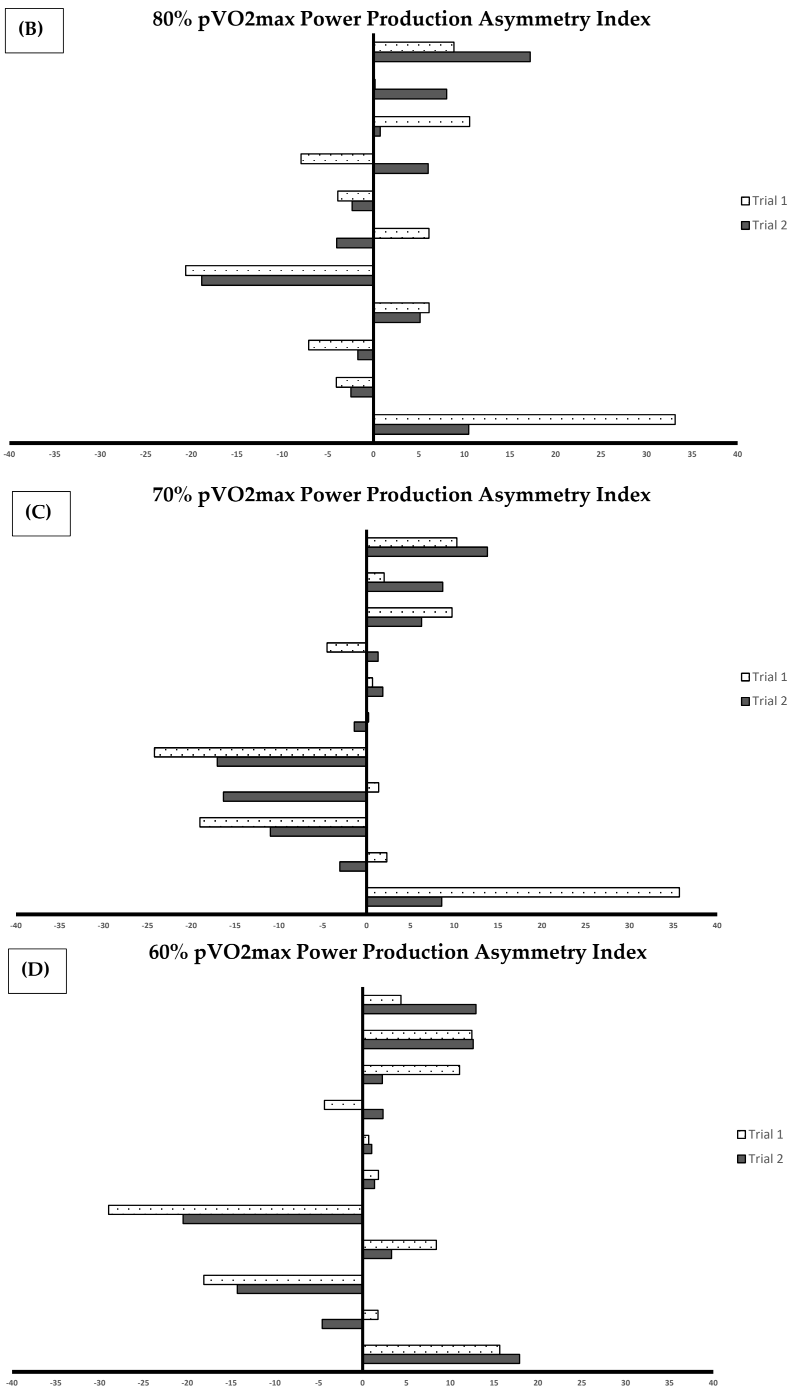

Figure 1. Asymmetry index at (**A**) 90%, (**B**) 80%, (**C**) 70%, and (**D**) 60% power pVO_2max.

4. Discussion

The current investigation sought to determine (1) if pedal force asymmetries were statistically significantly different during bouts of submaximal cycling at varying intensities separated by periods of recovery, and (2) if test–retest reliability exists for pedal force asymmetries. Based on previous investigations, it was hypothesized that pedal force asymmetries would not be statistically significantly different at different exercise intensities, and good-to-excellent test–retest reliability would be observed for pedal force asymmetries [12]. Based on the current results, both hypotheses were accepted.

There have been a number of investigations published on pedal force asymmetries with a focus on the impact of exercise intensity [2,10–12,26,27]. However, with several different devices, outcomes, and methodologies used in the assessment of pedal forces, there have been conflicting results reported. Initially, an inverse association was observed with exercise intensity and pedal force asymmetries, in that as exercise intensity increased, pedal force asymmetries decreased (i.e., they became more symmetrical) [13,27]. This was observed during a self-paced 40 km cycling time trial and during an incremental cycling test when comparing asymmetries observed above and below 90% of VO_2max [13,27]. However, later investigations have reported conflicting results, with pedal force asymmetries increasing with exercise intensity during an incremental cycling test [11]. Additionally, two investigations reported no difference in pedal force asymmetry between different exercise intensities [12,28].

A limitation of previous investigations is that the assessment of pedal force asymmetries has been carried out in a manner that does not account for the potential influence of the accumulation of exercise-induced fatigue during continuous bouts of cycling exercise. Analysis have been conducted comparing different phases of a self-paced time-trial and incremental cycling tests, which may result in comparing phases with varying degrees of fatigue. [11–13,27]. Evidence suggests lower limb asymmetries maybe heightened due to an accumulation of fatigue. Bishop et al. reported significant increases in lower limb asymmetries in jump height during single leg counter-movement jumps following bouts of repeated sprints [14]. Additionally, it was noted that lower limb asymmetries in jump height continued to increase with additional repeated bouts of sprints [14]. Additionally, lower limb asymmetries in jump height during single-leg counter-movement jumps were observed to increase 3.7 times from pre- to post-match in elite academy soccer players, and decreased towards baseline 48 h post-match [15]. Asymmetries in eccentric impulse and peak propulsive ground reaction forces were also observed to increase by 2.25 and 1.16 times from pre-match to post-match, respectively [15]. However, the time course for asymmetries to increase following the accumulation of exercise-induced fatigue is not fully understood, and neither is the degree of exercise-induced fatigue that is required to induce increases in asymmetries [29]. These investigations highlight the potential influence of exercise-induced fatigue on asymmetry measures, and provide evidence that accumulation of fatigue should be considered in cross-sectional study designs for assessing pedal force asymmetries during cycling.

When three-minute bouts of submaximal cycling were separated by five minutes of active recovery, no statistical significant differences were observed for pedal force asymmetries in the current investigation. This is an interesting finding that may suggest that the accumulation of fatigue may have influenced the magnitude of asymmetry in pedal forces previously reported [11,13,27]. Previous investigations have observed significant asymmetry in lean tissue mass in the lower limbs in elite cyclists when compared to controls, and this could influence the rate of accumulation of fatigue in each lower limb, resulting in differences in power production capabilities [30]. Asymmetry in lean tissue mass has been observed to influence force and power asymmetry during counter-movement jumps in collegiate athletes [3]. However, the relatively short bouts of exercise separated by extended bouts of recovery likely attenuated the development of fatigue, allowing for consistent application of force to the pedals during the assessments.

Assessment of asymmetry in force production has garnered much attention in recent years, with associations between asymmetry in force production and sport performance investigated across several sports [31–33]. However, differences in techniques used in the quantification of asymmetry and reporting of outcomes has made comparisons between investigations problematic at times. Researchers are attempting to address these issues in multiple ways, with one being reporting the reliability of asymmetry measures [1]. Recent investigations have reported high levels of reliability in peak force during isometric mid-thigh pulls and unilateral isometric quarter squats, with ICCs of 0.960 and 0.940 reported, respectively [34–36]. To the best of the knowledge of the current authors, this is the first investigation to report on the reliability of power production asymmetry during cycling, with excellent reliability observed at all exercise intensities. Previous investigations reporting on the reliability of asymmetry measures have reported much smaller CVs (0.96%

to 5.3%) [37–39]. However, in these investigations, CVs are lower because the CV has been evaluated before the quantifying of the asymmetry metric, when the standard deviations is smaller than the mean [1]. It has been suggested that when calculating the CV of asymmetry metric, rather than the trial data, the absolute reliability measures may be quite large; this suggests previous methods may have resulted in unmeasured errors [1]. Quantifying and understanding the true biological error associated with asymmetry metrics will allow for an accurate assessment of inter-limb asymmetry.

The current investigation is not without its limitations. The phase of the annual training program in which participants were in was not recorded or controlled for, and the effects of this on power production asymmetry have not been investigated. Additionally, the authors were not able to collect kinematic or body composition data of the lower limbs, and it is unclear if these factors influenced the asymmetry outcomes, especially the body composition data given the reported asymmetries in lower limb lean tissue mass in trained cyclists [30]. Future investigations should seek to investigate the influence of asymmetry in lower limb lean tissue mass on pedal force asymmetries. The current investigation only examined submaximal intensities, and negated maximal and supramaximal intensities. Though cyclists spend a majority of race time below VT_2/LT_2, ~16% of total race time maybe spent above VT_2/LT_2 and at or near maximal and supramaximal intensities [17]. Future investigations should aim to include these intensities.

5. Conclusions

No significant differences were observed at different submaximal exercise intensities for pedal force asymmetries when separated by bouts of active recovery. To the current authors' knowledge, this is the first investigation to attempt to control for the accumulation of fatigue during pedal force asymmetry assessments in trained cyclists. The current results suggest that the results of previous investigations may have been influenced by the accumulation of fatigue [11,13,27]. It is still unclear what the appropriate methodology is for assessing pedal force asymmetries, but future investigations should continue to work towards a standardized method that has potential applications in race and training settings.

Author Contributions: Conceptualization: J.W.F.III; methodology, J.W.F.III; analysis, V.E.N. and J.W.F.III; writing, J.W.F.III and V.E.N.; writing—review and editing, J.W.F.III and V.E.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Texas State University (protocol code 7800 approved 28 June 2021).

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bailey, C.A.; Sato, K.; McInnis, T.C. A Technical Report on Reliability Measurement in Asymmetry Studies. *J. Strength Cond. Res.* **2021**, *35*, 1779–1783. [CrossRef] [PubMed]
2. Carpes, F.P. On the Bilateral Asymmetry during Running and Cycling—A Review Considering Leg Preference. *Phys. Ther. Sport* **2010**, *11*, 136–142. [CrossRef] [PubMed]
3. Bell, D.R.; Sanfilippo, J.L.; Binkley, N.; Heiderscheit, B.C. Lean Mass Asymmetry Influences Force and Power Asymmetry during Jumping in Collegiate Athletes. *J. Strength Cond. Res.* **2014**, *28*, 884–891. [CrossRef] [PubMed]
4. Hoffman, J.R.; Ratamess, N.A.; Klatt, M.; Faigenbaum, A.D.; Kang, J. Do Bilateral Power Deficits Influence Direction-Specific Movement Patterns? *Res. Sport. Med.* **2007**, *15*, 125–132. [CrossRef]
5. Bishop, C.; Turner, A.; Read, P. Effects of Inter-Limb Asymmetries on Physical and Sports Performance: A Systematic Review. *J. Sport. Sci.* **2018**, *36*, 1135–1144. [CrossRef]
6. Barber, S.D.; Noyes, F.R.; Mangine, R.E.; Mccloskey, J.W.; Hartman, W. Quantitative Assessment of Functional Limitations in Normal and Anterior Cruciate Ligament-Deficient Knees. *Clin. Orthop. Relat. Res.* **1990**, *255*, 204214. [CrossRef]

7. Grindem, H.; Logerstedt, D.; Eitzen, I.; Moksnes, H.; Axe, M.J.; Snyder-Mackler, L.; Engebretsen, L.; Risberg, M.A. Single-Legged Hop Tests as Predictors of Self-Reported Knee Function in Nonoperatively Treated Individuals with Anterior Cruciate Ligament Injury. *Am. J. Sport. Med.* **2011**, *39*, 2347–2354. [CrossRef]
8. van Melick, N.; Meddeler, B.M.; Hoogeboom, T.J.; Nijhuis-van der Sanden, M.W.G.; van Cingel, R.E.H. How to Determine Leg Dominance: The Agreement between Self-Reported and Observed Performance in Healthy Adults. *PLoS ONE* **2017**, *12*, e0189876. [CrossRef]
9. Faria, E.W.; Parker, D.L.; Faria, I.E. The Science of Cycling: Physiology and Training—Part 1. *Sport. Med.* **2005**, *35*, 285–312. [CrossRef]
10. Bini, R.R.; Jacques, T.C.; Sperb, C.H.; Lanferdini, F.J.; Vaz, M.A. Pedal Force Asymmetries and Performance during a 20-km Cycling Time Trial. *Kinesiology* **2016**, *48*, 193–199. [CrossRef]
11. Bini, R.R.; Hume, P.A. Assessment of Bilateral Asymmetry in Cycling Using a Commercial Instrumented Crank System and Instrumented Pedals. *Int. J. Sport. Physiol. Perform.* **2014**, *9*, 876–881. [CrossRef]
12. Farrell, J.W. Effects of Exercise Intensity on Pedal Force Asymmetry during Cycling. *Symmetry* **2021**, *13*, 1499. [CrossRef]
13. Carpes, F.; Rossato, M.; Faria, I.; Mota, C.B. During a Simulated 40-km Cycling Time-Trial. *J. Sport. Med. Phys. Fit* **2007**, *47*, 51–57.
14. Bishop, C.; McAuley, W.; Read, P.; Gonzalo-Skok, O.; Lake, J.; Turner, A. Acute Effect of Repeated Sprints on Interlimb Asymmetries during Unilateral Jumping. *J. Strength Cond. Res.* **2021**, *35*, 2127–2132. [CrossRef]
15. Bromley, T.; Turner, A.; Read, P.; Lake, J.; Maloney, S.; Chavda, S.; Bishop, C. Effects of a Competitive Soccer Match on Jump Performance and Interlimb Asymmetries in Elite Academy Soccer Players. *J. Strength Cond. Res.* **2018**, *35*, 1707–1714. [CrossRef]
16. Blagrove, R.C.; Bishop, C.; Howatson, G.; Hayes, P.R. Inter-Limb Strength Asymmetry in Adolescent Distance Runners: Test-Retest Reliability and Relationships with Performance and Running Economy. *J. Sport. Sci.* **2021**, *39*, 312–321. [CrossRef]
17. Sanders, D.; van Erp, T. The Physical Demands and Power Profile of Professional Men's Cycling Races: An Updated Review. *Int. J. Sport. Physiol. Perform.* **2021**, *16*, 3–12. [CrossRef]
18. George, J.D.; Stone, W.J.; Burkett, L.N. Non-Exercise VO_2max Estimation for Physically Active College Students. *Med. Sci. Sport. Exerc.* **1997**, *29*, 415–423. [CrossRef]
19. Jamnick, N.A.; By, S.; Pettitt, C.D.; Pettitt, R.W. Comparison of the YMCA and a Custom Submaximal Exercise Test for Determining VO_2max. *Med. Sci. Sport. Exerc.* **2016**, *48*, 254–259. [CrossRef]
20. Driller, M.W. The Reliability of a 30-Minute Performance Test on a Lode Cycle Ergometer. *J. Sci. Cycl.* **2012**, *1*, 7.
21. Sedgeman, D.; Dalleck, L.; Clark, I.; Jamnick, N.; Pettitt, R. Analysis of Square-Wave Bouts to Verify VO_2max. *Int. J. Sport. Med.* **2013**, *34*, 1058–1062. [CrossRef] [PubMed]
22. Virgile, A.; Bishop, C. A Narrative Review of Limb Dominance: Task Specificity and the Importance of Fitness Testing. *J. Strength Cond. Res.* **2021**, *35*, 846–858. [CrossRef] [PubMed]
23. Fleiss, J.L. Reliability of Measurement. In *The Design and Analysis of Clinical Experiments*; John Wiley & Sons: Hoboken, NJ, USA, 1986. [CrossRef]
24. Olejnik, S.; Algina, J. Generalized Eta and Omega Squared Statistics: Measures of Effect Size for Some Common Research Designs. *Psychol. Methods* **2003**, *8*, 434–447. [CrossRef] [PubMed]
25. Pauw, K.D.; Roelands, B.; Cheung, S.S.; de Geus, B.; Rietjens, G.; Meeusen, R. Guidelines to Classify Subject Groups in Sport-Science Research. *Int. J. Sport. Physiol. Perform.* **2013**, *8*, 111–122. [CrossRef] [PubMed]
26. Bini, R.R.; Jacques, T.C.; Carpes, F.P.; Vaz, M.A. Effectiveness of Pedalling Retraining in Reducing Bilateral Pedal Force Asymmetries. *J. Sport. Sci.* **2017**, *35*, 1336–1341. [CrossRef]
27. Carpes, F.P.; Rossato, M.; Faria, I.E.; Mota, C.B. During an Incremental Exercise Cyclists Improve Bilateral Pedaling Symmetry. *Braz. J. Biomot.* **2008**, *2*, 155–159.
28. García-López, J.; Díez-Leal, S.; Larrazabal, J.; Ogueta-Alday, A. No Bilateral Asymmetry during Pedalling in Healthy Cyclists of Different Performance Levels. In Proceedings of the 33rd International Conference of Biomechanics in Sports, Poitiers, France, 29 June–3 July 2015; p. 4.
29. Heil, J.; Loffing, F.; Büsch, D. The Influence of Exercise-Induced Fatigue on Inter-Limb Asymmetries: A Systematic Review. *Sport. Med.-Open* **2020**, *6*, 39. [CrossRef]
30. Pimentel, R.E.; Baker, B.S.; Soliday, K.; Reiser, R.F. Bone Mineral Density and Lean Mass Asymmetries Are Greater in Cyclists than Non-Cyclists. *J. Sport. Sci.* **2019**, *37*, 2279–2285. [CrossRef]
31. Bishop, C.; Read, P.; McCubbine, J.; Turner, A. Vertical and Horizontal Asymmetries Are Related to Slower Sprinting and Jump Performance in Elite Youth Female Soccer Players. *J. Strength Cond. Res.* **2021**, *35*, 56–63. [CrossRef]
32. dos Santos, K.; Pereira, G.; Papoti, M.; Bento, P.C.; Rodacki, A. Propulsive Force Asymmetry during Tethered-Swimming. *Int. J. Sport. Med.* **2013**, *34*, 606–611. [CrossRef]
33. Hart, N.H.; Nimphius, S.; Spiteri, T.; Newton, R.U. Leg Strength and Lean Mass Symmetry Influences Kicking Performance in Australian Football. *J. Sport. Sci. Med.* **2014**, *13*, 157–165.
34. Bishop, C.; Read, P.; Chavda, S.; Jarvis, P.; Turner, A. Using Unilateral Strength, Power and Reactive Strength Tests to Detect the Magnitude and Direction of Asymmetry: A Test-Retest Design. *Sports* **2019**, *7*, 58. [CrossRef]
35. Bishop, C.; Read, P.; Lake, J.; Loturco, I.; Dawes, J.; Madruga, M.; Romero-Rodrigues, D.; Chavda, S.; Turner, A. Unilateral Isometric Squat: Test Reliability, Interlimb Asymmetries, and Relationships with Limb Dominance. *J. Strength Cond. Res.* **2021**, *35*, S144–S151. [CrossRef]

36. Dos'Santos, T.; Thomas, C.; Comfort, P.; McMahon, J.J.; Jones, P.A.; Oakley, N.P.; Young, A.L. Between-Session Reliability of Isometric Midthigh Pull Kinetics and Maximal Power Clean Performance in Male Youth Soccer Players. *J. Strength Cond. Res.* **2018**, *32*, 3364–3372. [CrossRef]
37. Bishop, C.; Read, P.; Bromley, T.; Brazier, J.; Jarvis, P.; Chavda, S.; Turner, A. The Association between Interlimb Asymmetry and Athletic Performance Tasks: A Season-Long Study in Elite Academy Soccer Players. *J. Strength Cond. Res.* **2022**, *36*, 787–795. [CrossRef]
38. Madruga-Parera, M.; Bishop, C.; Fort-Vanmeerhaeghe, A.; Beltran-Valls, M.R.; Skok, O.G.; Romero-Rodríguez, D. Interlimb Asymmetries in Youth Tennis Players: Relationships with Performance. *J. Strength Cond. Res.* **2020**, *34*, 2815–2823. [CrossRef]
39. Pardos-Mainer, E.; Casajús, J.A.; Gonzalo-Skok, O. Adolescent Female Soccer Players' Soccer-Specific Warm-Upeffects on Performance and Inter-Limb Asymmetries. *Biol. Sport* **2019**, *36*, 199–207. [CrossRef]