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Original Article

Jump test asymmetry profiles of elite trials cyclists.

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Abstract
Bike trials is a cycling discipline in which riders navigate a series of obstacle courses on their bikes. As many of the techniques used in trials riding are acyclic, riders will display a natural preference as to which foot is on the front pedal. The primary aim of this study was to try to identify if this unique riding style creates a sport-specific inter-limb asymmetry profile during a range of common jump tests. Eight elite trials riders (mean age 20.0 ± 0.9 years, height 178.5 ± 6.8 cm, weight 76.1 ± 10.4 kg) completed three repetitions each of countermovement jump, single leg countermovement jump and single leg hop tests. There were no significant asymmetries between the overall group means for the jump tests (absolute asymmetry: countermovement jump 5.4 ± 3.6%; single leg countermovement jump 10.0 ± 5.4%; and single leg hop 5.9 ± 4.0%). There were however significant ($p<0.05$) individual asymmetries found in all of the jump tests and meaningful asymmetries (percentage asymmetry greater than coefficient of variation) in both of the single leg tests. The direction of asymmetry was shown to be variable across the different tests (Fleiss' Kappa = -0.34). Some participants also showed meaningful and significant differences in the movement strategies used within a test, though again there were no significant differences in the group means. The findings suggest inter-limb asymmetries are highly task specific and there was no evidence to suggest that trials riders develop specific asymmetries due to the asymmetrical physical demands of their sport.
Athletic Performance, Bike Trials, Cycling.

Introduction

Trials is a cycling discipline in which participants attempt to navigate a number of obstacle courses, called sections, on their bikes. Some of the key techniques in overcoming the challenge of a trials section include variations of hops or jumps whilst balancing on the rear wheel of the bike (Albano et al., 2020). Due to these techniques being acyclic in nature, a rider will usually display a preference as to which foot is on the front pedal (Vastola et al., 2016). This lateral preference is a normal reaction in humans when presented with a given task, for example 90% of people write with their right hands (Carpes et al., 2010) and footballers will have a foot with which they prefer to kick the ball (Maloney, 2019).

The theory of mechanotransduction (Khan & Scott, 2009) suggests that the body's cells will respond to a mechanical stress imposed upon them and adapt in order to cope with the demands. Consequently, if asymmetrical stresses are placed upon different limbs this could produce asymmetrical adaptations. This may be the case with trials riders as whilst both feet are on the bike they are positioned differently and perform different actions, a situation described as being bilateral asymmetric (Guiard, 1987; Virgile & Bishop, 2021). A preliminary (unpublished) time-motion analysis of the 2019 UCI Trials World Championships 20" Elite Men's final showed that riders spent 74.3 ± 9.7% of their time performing acyclic bilateral asymmetric actions. As the mechanical stresses experienced by an athlete are a result of their sporting activity, then the magnitude of asymmetry will be influenced by the exposure to that sport (Bishop, Read, et al., 2021; Hart et al., 2016; Maloney, 2019). Within competitive bike trials a high volume of training is required to reach the level of technical mastery needed to be successful (Tarnas et al., 2012). It would therefore be logical to assume that a pattern of sport specific asymmetry may develop in trials cyclists due to the asymmetrical physical demands and high volumes of training. Asymmetrical adaptations have been shown in athletes from other sports due to the sports' demands. For example the racket arm of tennis players has been shown to have a greater lean mass, bone mass, and density than the opposite arm (Sanchis-Moysi et al., 2010). Snowboarders have also shown asymmetries depending on their competitive discipline and their preferences in bodyweight distribution on the board (Vernillo et al., 2016). Boardercross and freestyle snowboarders who use an equal weight distribution between legs display smaller differences in single leg jumping performance (2.0 and 2.2%) when compared to alpine disciplines where the majority of load is on one leg (11.3%).

Jumping is a common method of both physical testing and training within sports performance and inter-limb asymmetries found whilst jumping are a popular field of investigation across a range of sports (Bishop,

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Turner, et al., 2018; Carpes et al., 2010; Maloney, 2019). As jumping has been shown to have biomechanical similarities to rear wheel bike techniques (Albano et al., 2020) it may be an ecologically valid method of assessing inter-limb asymmetries in trials cyclists. Whilst there has been previous investigation into jump test performance in trials riders (Albano et al., 2019; Thomas et al., 2018) these study have exclusively used bilateral jumps (countermovement jumps, squat jumps and standing broad jumps) and have not reported any asymmetries. In order for an asymmetry profile to be complete a range of jump tests are required because inter-limb asymmetry has been shown to be a task specific concept with large variations found between horizontal, vertical, bilateral and unilateral tests (Bishop, Pereira, et al., 2020; Bishop, Weldon, et al., 2021; Maloney, 2019; Read et al., 2021; Virgile & Bishop, 2021). An asymmetry profile should also report on both the magnitude and direction of any asymmetries discovered (Bishop, 2021; Jordan et al., 2015; Pardos-Mainer et al., 2021; Virgile & Bishop, 2021). This is especially true for trials cyclists as they have a clear differentiation between the back foot (BF) and front foot (FF) which leads to the possibility that a pattern could develop towards one of these.

A confounding factor when investigating inter-limb asymmetries in jump tests is the possible use of compensatory movement strategies. Whilst there may be small performance asymmetries being exhibited, there may be larger variations in how these values were achieved. Compensatory movement strategies without a loss of performance have been demonstrated whilst recovering from injury (King et al. 2021) and when fatigued (Kennedy & Drake, 2017). This ability to mask deficiencies mean that performance test scores should not be considered in isolation when assessing an athlete, but rather a combination of both the performance outcomes and the movement strategy used (Kotsifaki et al., 2020). Indeed Bishop, Weldon, et al. (2021) state that over a given time period movement strategy may be more sensitive to changes in inter-limb asymmetry than performance scores. Several efforts have been made to compare asymmetries to measures of sporting performance in order to quantify acceptable limits, however reviews caried out by Maloney (2019) and Khudik et al. (2018) found several contradictory findings across and within tasks and concluded that a clear link between asymmetries and sporting performance can not be determined. Whilst some authors have tried to propose arbitrary thresholds of acceptable inter-limb asymmetry these have been shown to be a unusable concept due to the contradictory evidence base and the need to individualise training interventions (Bishop, 2021; Kozinc & Šarabon, 2020; Read et al., 2021). Similarly, whilst exploring the relationship between lower limb asymmetry profiles and injury risk Helme et al. (2021) concluded that whilst an association may possibly exist there is currently only a low-quality evidence base. Given these mixed findings it is important not to over-extrapolate results from various performance tests and populations to apply them to other situations, but rather try to develop context specific guidelines (Virgile & Bishop, 2021). These guidelines have not yet been developed for trials riders. Trials cycling is a unique discipline of cycling and has received little attention in the peer-reviewed literature, consequently there is a lack of information available on inter-limb asymmetries in this sporting population. There are commonly held beliefs within the community that there are physical and performance asymmetries caused by trials riding, but to date there has been no evidence of their existence. The aim of this study was therefore to investigate if the physical demands of bike trials create an identifiable sport specific inter-limb asymmetry across a range of common jump tests.

Methods

Participants

Eight elite trials riders were recruited to participate in the study. Table 1 shows the participant characteristics and a break-down of the categories in which they compete. Elite status was confirmed by the requirement that all participants had to have competed at European and World level during the previous competition season.

Table 1. Participant characteristics.

Category	n	Height (cm)	Weight (kg)	Age (years)	UCI World Ranking
Female	2	169.5 ± 2.1	61.5 ± 0.8	21.0 ± 0.0	
Male 20”	4	180.8 ± 5.3	81.8 ± 9.8	19.8 ± 1.0	
Male 26”	2	183.0 ± 4.2	79.6 ± 10.6	19.5 ± 0.7	
Total	8	178.5 ± 6.8	76.1 ± 10.4	20.0 ± 0.9	23.3 ± 19.7

All participants provided informed consent prior to participation and were screened for health problems and injuries via a Physical Activity Readiness Questionnaire. In order to exclude asymmetries due to injury all participants had to be participating in unrestricted training at the time of testing and could not have suffered a severe injury (defined as a training time loss of greater than 28 days) within the proceeding 12 months (Bishop, Weldon, et al., 2021; Read et al., 2021). There were no participants excluded due to these criteria. Ethical approval for the study was granted by St Mary’s University, London.

Procedures

A semi-standardised RAMP warm-up (Jeffreys, 2007) was performed consisting of five minutes low intensity cycling, 20 repetitions each of lunges, press-ups and squats and two minutes of mobility exercises. The participants were then familiarised with the jump testing procedures by performing 2-3 practise jumps, with these jumps also acting as the ‘potentiation’ phase of the RAMP warm-up.

Countermovement jump (CMJ) and single leg countermovement jump (SL-CMJ). Both the CMJ and SL-CMJ were performed on FDLite force platforms (Vald Performance Pty Ltd, Newstead, Australia), with a sampling rate of 1000Hz. At the beginning of each jump the participants were instructed to remain still for one second in order for the weight to be determined and ensure accuracy of detecting the start of the movement (Harry et al., 2020; McMahon et al., 2018). The legs were tested alternately during the SL-CMJ, starting with a randomised selection between the two. The participants performed a countermovement to a self-selected depth before jumping as high as possible. The participants were required to keep their legs extended during flight and to land on the force platforms maintaining their hands on their hips at all times. To ensure that the landing was controlled the participants were required to remain standing still on the platform for an additional second after landing. Jump height was calculated using the impulse-momentum method (McMahon et al., 2018) and for the CMJ the relative contribution of the two legs was quantified by comparing the net peak take-off force generated by each leg.

Single leg hop (SL-Hop). The participants began stood on the leg being tested with their hands on their hips and their toes behind a line on the ground. The legs were tested alternately, starting with a randomised selection between the two. Participants performed a countermovement to a self-selected depth before jumping as far forwards as possible. Participants were required to hold the landing position for a second to ensure a controlled landing and to allow for measurement to be taken. The distance was recorded from the starting line to the heel of the foot at landing. Three trials were recorded for each of the jumping tests, with one minute's rest between each repetition and two minutes between the different jump tests. Any deviation from the desired jumping technique resulted in the trial being retaken after one minute of rest. To quantify the movement patterns used during the SL-CMJ and SL-Hop footage was recorded at 120fps using a GoPro Hero5 camera (GoPro Inc, San Mateo, USA) placed perpendicular to the participant at the starting position. The footage was analysed using Kinovea software (v0.9.3, J. Charmant) to record the peak dorsiflexion, hip flexion and knee flexion during the countermovement (using joint angle definitions from Dingwell et al., 2008). As the SL-CMJ was performed on a force platform it was also possible to record the time to net peak take-off force for comparison between the limbs. The start of movement was defined as the time point at which the recorded force dropped below five standard deviations of that recorded during the weighting period (McMahon et al., 2018).

Statistical analysis

All data analysis was performed using Excel (Microsoft, Redmond, USA) and SPSS 26 (IBM, Armonk, USA). The mean of the three trials of each test was analysed (Virgile & Bishop, 2021). Cronbach's alpha and the coefficient of variation (CV) were used to determine test reliability. The back foot (BF) and front foot (FF) preference was determined by asking the rider their normal riding stance. Asymmetry during the CMJ was calculated by comparing the net peak take-off forces using the using the Bilateral Asymmetry Index 1 (Bishop, Read, et al., 2018) modified to state BF and FF rather than dominant and non-dominant, as shown in Equation 1. The percentage difference method (Equation 2) was used to quantify the absolute magnitude of asymmetry of the kinematic and kinetic variables recorded during the SL-CMJ and SL-Hop tests (Bishop, Read, et al., 2018). To calculate both the direction and magnitude of asymmetry the Excel 'IF function' *IF(FF<BF,1,-1) was added to the end of the corresponding equation (Bishop, Turner, et al., 2020). In accordance with Bishop (2021) a 'meaningful' asymmetry was defined as an asymmetry result from the above equations which was greater than the coefficient of variation for the corresponding test. The Shapiro-Wilks test was used to test for normal distribution of the data. Individual Student's paired t-tests were used to test for significant differences between test results. The Kappa coefficient (k) and Fleiss' Kappa coefficient were used to determine agreement between the direction of asymmetry during the different jump tests. Significance was set a priori at $p < 0.05$.

Equation 1. Bilateral Asymmetry Index 1.

$$BAI\ 1 = \frac{FF - BF}{FF + BF} 100$$

Equation 2. Percentage difference.

$$\text{Percentage difference} = \frac{100}{(\text{max value})} (\text{min value})(-1) + 100$$

Results

All data were normally distributed. Mean test performance and the test reliability data are displayed in Table 2. Individualised CV values for each of the jump tests are also shown in Figures 3-5.

Mean absolute asymmetry for the CMJ was 5.4 ± 3.6%, SL-CMJ was 10.0 ± 5.4% and for the SL-Hop was 5.9 ± 4.0%. There were no significant differences in mean absolute asymmetries for any jump test. In contrast to the overall findings, when the participants were examined individually there were both meaningful and significant asymmetries found. None of the participants showed a consistent asymmetry direction across the different tests with an overall Fleiss' Kappa coefficient of -0.34. The agreement between the direction of asymmetry displayed in the SL-CMJ and SL-Hop was k = 0.25. Due to the highly variable directions and magnitudes of asymmetry displayed during the different tests Figures 1-3 break the results down into individualised results. When examining the movement strategies used in the single leg jumps there were no significant differences in the overall group means. Individualised analysis does however reveal both meaningful and significant asymmetries and so this analysis is presented in Table 3.

Table 2. Mean test performance and test reliability. BF = Back foot, FF = Front foot.

		Height/distance (cm)	*Cronbach's alpha*	*CV (%)*
CMJ		***36.9 ± 6.9***	***0.99***	***19.0***
SL-CMJ	***BF***	***16.7 ± 3.0***	***0.93***	***11.4***
	FF	***17.0 ± 2.7***	***0.94***	***10.5***
SL-Hop	***BF***	***165.6 ± 18.9***	***0.98***	***18.0***
	FF	***161.8 ± 16.9***	***0.93***	***15.8***

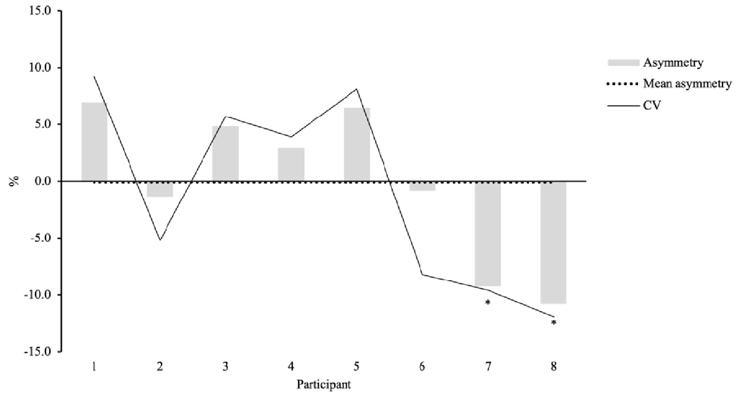

Figure 1. Mean asymmetry values for the net peak take-off force in the CMJ. * = significant asymmetry p<0.05. Positive values indicate an asymmetry towards the front foot, negative values towards the back foot.

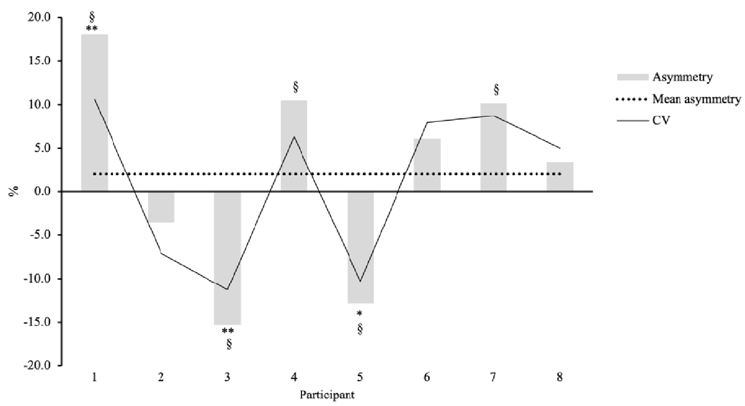

Figure 2. Mean asymmetry values for jump height in the SL-CMJ. § = meaningful asymmetry, * = significant asymmetry p<0.05, ** = significant asymmetry p<0.01. Positive values indicate an asymmetry towards the front foot, negative values towards the back foot.

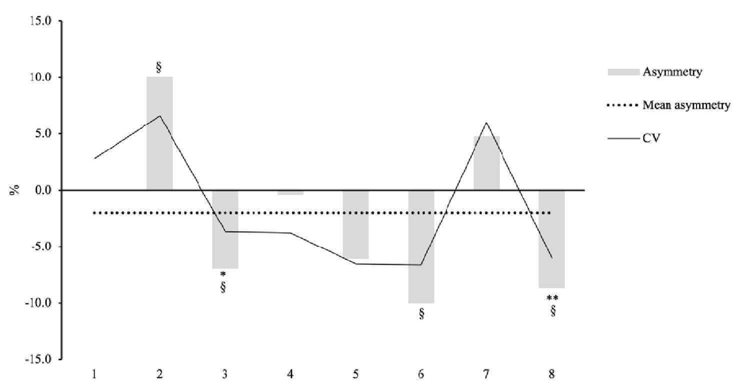

Figure 3. Mean asymmetry values for jump distance in the SL-Hop. § = meaningful asymmetry, * = significant asymmetry p < 0.05, ** = significant asymmetry p < 0.01. Positive values indicate an asymmetry towards the front foot, negative values towards the back foot.

Table 3. Mean asymmetry values (percentage difference) for the minimum internal joint angles during the countermovement of the SL-CMJ and SL-Hop (plus time to net peak take-off force in the SL-CMJ). Positive values indicate an asymmetry towards the front foot, negative values towards the back foot.

	SL-CMJ				SL-Hop		
Participant	Ankle	Hip	Knee	Time to peak force	Ankle	Hip	Knee
1	2.2[§]	6.9[§**]	6.3[§]	-30.9[§]	-6.8[§]	1.6	2.3
2	0.4	0.0	6.2[§]	-40.5[§**]	-4.6[§]	4.0[§]	-4.4[§]
3	-2.2	-0.8	-5.4[§]	6.5[§]	-5.5[§]	10.0[§]	-5.4[§]
4	-1.3	-2.7[§]	2.0	12.8[§]	-3.2	2.0	3.1
5	3.2[§]	-4.2[§]	-3.5	10.8	2.6	-4.3	4.9[§]
6	-0.9[§]	-10.7[§**]	5.4[§**]	8.7	4.4	-8.6[§]	-1.8
7	0.7	-15.3[§]	2.7[§]	1.6	0.0	6.0	4.0[§]
8	6.8[§]	-7.7[§]	6.3[§]	13.3	2.0[§]	-1.2	10.8[§*]
Mean	1.1	-4.3	2.5	-2.2	-1.4	1.2	1.7

[§] = Meaningful asymmetry, * = significant asymmetry $p < 0.05$, ** = significant asymmetry $p < 0.01$.

Discussion

The primary aim of this study was to investigate if the physical demands of bike trials create an identifiable sport specific inter-limb asymmetry across a range of common jump tests. The results show little agreement between the direction of asymmetry in the bilateral and unilateral, horizontal and vertical tests that would suggest a consistent adaptation to the demands of the sport. Furthermore, the level of agreement for direction of asymmetry between the SL-CMJ and SL-Hop was low (k = 0.25), reinforcing that there are individual movement preferences for any given task. This finding is supported by Daly and Cavanagh (1976) and Virgile and Bishop (2021) who also concluded that the direction of asymmetry within a test is specific to the task being completed and unrelated to limb preference.

Bike trials is an under-researched sport and whilst there have been studies looking at the anthropometrics (Tarnas & Wielinsky, 2005) and CMJ performance (Albano et al., 2019; Thomas et al., 2018) of trials riders neither of these studies have reported on any asymmetries found. The results of this study cannot therefore be directly compared to previous research in trials riders. The SL-CMJ asymmetry values reported in this study (10%) are similar to those reported in the snowboarding literature which is also classed as a bilateral asymmetric sport. Danielsson (2010) reported asymmetries in the SL-CMJ of 9.9% for freestyle snowboarders whilst Vernillo et al. (2016) reported 11.3% for alpine snowboarders. In previous jump testing research, the SL-CMJ has often displayed a greater percentage asymmetry than the SL-Hop. For example, in adolescent soccer players Pardos-Mainer et al. (2021) reported a mean 11.6% asymmetry in SL-CMJ performance and 4.8% in the SL-Hop whilst Bishop, Read, McCubbine, et al. (2021) reported 12.5% and 6.8% respectively. Similar results (SL-CMJ 10.2% and SL-Hop 3.5%) have also been reported in a group of male and female volleyball players (Kozinc & Šarabon, 2020). The results of this study (SL-CMJ 10.0% and SL-Hop 5.9%) are therefore comparable with previously reported findings and are not unique to trials riders.

In terms of absolute performance, the CMJ performance of this study (36.9 cm) is below previously reported values for elite trials cyclists of 44.0 cm (Albano et al., 2019) and 48.0 cm (Thomas et al., 2018). This may be due to the population differences as this study includes male and female riders using both 20” and 26” bikes, Thomas et al. (2018) includes 20” and 26” male riders and Albano et al. (2019) only reported on male 20” riders. If the results of the male 20” riders were to be extracted from each study’s participants their mean jump height would be 42.8 cm (this study), 44 cm (Albano et al., 2019) and 50 cm (Thomas et al., 2018). The SL-CMJ performances (BF 16.7cm, FF 17.0cm) are also in line with those of another bilateral asymmetric sport, freestyle snowboarding of BF 17.4cm and FF 19.3cm (Danielsson, 2010).

With regards to asymmetry, care should be taken when looking at group means as they can disguise large individual variations (Bishop, Lake, et al., 2018; Cushion et al., 2021). Participants 3 and 5 showed significant asymmetries towards the BF in the SL-CMJ despite the fact that the overall group mean was (insignificantly) towards the FF. The overall group mean for time to net peak take-off force during the SL-CMJ also suggested that the FF was faster than the BF even though the BF was faster in six out of the eight participants. Given that pre-defined asymmetry thresholds based on group means or arbitrary values have been shown to be unworkable concepts (Bishop, 2021; Read et al., 2021), it has been recommended that an individualised ‘meaningful asymmetry’ is used to help individualise the interpretation of asymmetry test results (Bishop, 2021). This meaningful asymmetry is defined as a percentage difference value above that of the individual’s test CV. In this way the asymmetry ‘signal’ can be differentiated from the ‘noise’ of the natural testing variability irrespective of the task or metric being measured. Using this definition, none of the participants showed a meaningful asymmetry in the CMJ, five in the SL-CMJ and four in the SL-Hop, further highlighting the individual task specific nature of asymmetries.

In addition to the performance test scores, it is important to assess how the performances were achieved (Bishop, 2021; Bishop, Weldon, et al., 2021; King et al., 2021). Cushion et al. (2021) found that whilst global coordination strategies may exist for a task there can be adaptations to the strategy based upon individual constraints. Physical capacities could be one such a constraint and altered movement patterns could present themselves in order to compensate for a deficiency or injury (King et al., 2021; Kotsifaki et al., 2021; Read et al., 2020). This capacity to adapt and compensate in order to produce a symmetrical performance highlights the need for a coach to assess not just performance scores but also how they were achieved. Examples in this study include participant 6 who lacked meaningful or statistical asymmetries in SL-CMJ height and the time to peak force, yet had meaningful and significant asymmetries in flexion of both the hip and knee and a meaningful dorsiflexion asymmetry. The FF ankle and hip flexed more than those of the BF whilst the knee flexed less and so when combined the two legs produced similar overall performance outcomes. Similarly participant 2 showed neither meaningful or significant asymmetries in the SL-CMJ height or ankle and hip flexion and yet the BF was 40.5% slower to reach peak force than the FF. Kotsifaki et al. (2021) showed that the physical demands of horizontal and vertical jumping are different, with the SL-CMJ showing a relatively equal contribution from the ankle, knee and hip during take-off, whereas the SL-Hop is primarily dependant on ankle and hip contributions with a limited contribution from the knee. Patterns such as these could help a coach understand where the differences lie and reinforces the need for both horizontal and vertical tests to be performed.

The different metrics being reported within each jump test of this study were highly variable. For example, during the SL-CMJ one participant displayed a 3.5% asymmetry in jump height, 0.0% asymmetry in peak hip flexion, 6.2% knee flexion and a 40.5% asymmetry in the time to peak force production. Previous research into the SL-CMJ has also shown similar variations between metrics in volleyball players, reporting a 3.6% asymmetry in force production, 6.5% in power production and 10.2% asymmetry in jump height (Kozinc & Šarabon, 2020). These findings support the statement from Bishop (2021) that asymmetry is metric dependent and task specific in nature. This suggests the metrics being reported during a test are just as important a consideration as which tests were performed when analysing a battery of jump tests. Bishop, Weldon, et al. (2021) also found that some metrics were more stable than others for their direction of asymmetry across the duration of a season, with reactive strength index showing more stability than jump height. Therefore, a limitation of this study is that the testing occurred at a single time point during the pre-season training period. If inter-limb asymmetries can occur due to the physical demands of the sport and training requirements (Bishop, Read, et al., 2021; Hart et al., 2016; Maloney, 2019), it could be possible that the results found during this study may be impacted by the training period. The study was conducted in the pre-season period, a time when the volume of gym training and mountain bike/road cycling are at their highest, the findings may therefore differ if the study were to be repeated during the competitive season, where the volume of trials riding is at its greatest. Bishop, Read, et al. (2020) compared the direction of asymmetry in SL-CMJ tests performed by soccer players throughout a season and demonstrated Kappa coefficients ranging from slight (-0.06) to substantial (0.77). Similarly, Bishop, Weldon, et al. (2021) investigated cricket players, reporting Kappa coefficients ranging from fair (-0.21) to substantial (0.72) and significant differences in jump height asymmetry between the middle and end of the season, further supporting the evidence that inter-limb asymmetry can vary throughout a season. Over a shorter time period Daly and Cavanagh (1976) investigated torque asymmetries during 10-second cycling sprints on two different days and found an agreement of only 0.47 across the two days. They also quantified strength asymmetries by means of a cycling specific isometric strength test and found that only 13 of the 20 participants showed a consistent mean direction of asymmetry across the two days. Virgile and Bishop (2021) state that due to the large possible fluctuations in an athlete's asymmetry scores regular testing should be conducted throughout a season in order to detect and monitor this phenomenon. It is therefore recommended that future investigations include testing at multiple time points across the training year.

Conclusion

The results of this study were consistent with previous findings that inter-limb asymmetries are task and metric specific and very highly individual in nature. Despite the unique demands of bike trials and the training required to reach elite status no sport specific pattern of asymmetries was identified in this study. These could be important considerations for coaches and medical staff working with trials riders as they challenge the assumption that there will be functional performance differences between the back and front feet due to the asymmetrical demands of the sport. The movement strategy used whilst performing a jump test may show large inter-limb differences, even if there are only small asymmetries in performance scores. Assessment of a rider's inter-limb asymmetry can not therefore rely on performance scores alone but should also take into consideration how the performances were achieved.

Conflicts of interest

The authors declare no conflicts of interest.

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