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Evaluating Novel Methods of Classifying Interlimb Asymmetries Within Collegiate American Football Players

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ABSTRACT

International Journal of Exercise Science 15(6): 473-487, 2022. Over the last few years, researchers and sport scientists have expressed an increased interest in the effects of interlimb asymmetry on aspects of sport performance such as jumping, sprinting, and changing direction. This study aimed to evaluate the diagnostic utility of three different means of classifying asymmetry to highlight if a 6-week resistance training intervention can meaningfully reduce levels of asymmetry, and to determine the relation between asymmetry reduction and improvements in change of direction (CoD) performance, if any. Eighteen, division-two collegiate American football skill position players completed all pre- and post-intervention procedures. These procedures involved the completion of the Bulgarian Split Squat (BSS) exercise from which asymmetries in relative average power (Rel.AP), and relative peak power (Rel.PP) were derived. Additionally, participants completed three repetitions within the 505 and L-drill tests to quantify CoD performance. Results from our study show that participants classified as asymmetrical, exhibiting observed asymmetry in Rel.PP scores larger than the sample mean plus one standard deviation, had the greatest likelihood of reducing asymmetry (OR = 6.99, 95% CI: 1.4, 12.5) and improving L-drill performance (OR = 1.33, 95% CI: -2.1, 4.8). Further, our training intervention meaningfully reduced Rel.AP asymmetry ($p = 0.027$, Cohen's $d = 0.73$). At the group level, these reductions in asymmetry were accompanied by improvements in L-drill performance that were larger than the sample smallest worthwhile change (SWC). At the individual level, however, change scores in asymmetry and change scores in CoD performance only showed small, non-significant correlations.

KEY WORDS: Interlimb asymmetry, American football, asymmetry interpretation

INTRODUCTION

Across the existing literature, interlimb asymmetry is conceptualized as the difference in performance or function of one limb with respect to the other (6). In a recent paper by Dos'Santos et al. the authors highlighted that interlimb asymmetries are often categorized into one of the following: "anatomical or morphological asymmetries; flexibility asymmetries; strength asymmetries; strategy asymmetries; as well as skill or outcome asymmetries" (14). Recent investigations have tried to show connections between asymmetries and sport performance tasks within healthy, non-injured, athletic populations. Many of these studies have focused on strength or power-based asymmetries and the potential effects of these variables on sport-related key performance indicators such as sprinting, jumping, and changing direction (2, 5, 9, 22, 23, 29). For instance, Bishop et al. has shown interlimb asymmetries derived from vertical jumps to be associated with decreased speed, change of direction speed, as well as jumping performance within a sample of elite academy soccer players (2). Further, within a different study, Madruga-Parera et al. highlighted that larger interlimb asymmetries, derived from an iso-inertial device, were related to reduced change of direction performance within a sample of youth handball players (22).

Studies have shown relationships between asymmetry and performance outcomes, but researchers and practitioners alike are still working out how to best interpret the meaningfulness of their athletes' asymmetry data. Some authors have proposed specific asymmetry thresholds for practitioners to use. Goals of this work include helping them determine whether an athlete's asymmetry may be attenuating performance or increasing risk for sport-related injuries (19, 27, 28). However, the arbitrary nature of these thresholds has been criticized in recent papers as they do not account for the task-, and metric-dependent nature of interlimb asymmetry (1, 4, 14, 30). Recent work has tried to account for these limitations. Novel methods of interpreting interlimb asymmetry, which account for task- and metric-dependent nature, have been proposed. According to Bishop, practitioners may consider an asymmetry score as meaningful, or potentially influential, whenever it exceeds the within-subject test variability score for a given test or metric, often measured by the coefficient of variation (CV) (1). Further, Dos'Santos et al. proposed that athletes may be classified as symmetrical, possessing small to moderate levels of asymmetry, or possessing high or extreme levels of asymmetry, based on their asymmetry score within a given test, with regards to the population mean and standard deviation (14). More specifically, athletes may be classified as possessing small to moderate levels of asymmetry, whenever their asymmetry score exceeds a threshold made up of the population mean plus the smallest worthwhile change (M + SWC). On the other hand, athletes may be classified as possessing high or extreme levels of asymmetry whenever their asymmetry score exceeds a threshold made up of the population mean plus the between-subject standard deviation (M + SD) for a specific test (14).

Research investigating the effects of specific training interventions on interlimb asymmetry and performance within sport-related key performance indicators is rather scarce. The existing literature is replete with different populations, testing procedures, training procedures, and outcome measures which complicate comparison and meaning making (8, 11, 12, 13, 15). It has been suggested that future investigations should compare the training induced percentage reduction in asymmetry to the variability of error of the specific test (7).

Our study will be among the early investigations to consider different methods of asymmetry classification, compare responsivity to a training intervention, and offer insight on the diagnostic utility of proposed asymmetry thresholds that account for task and metric-dependent nature of tasks. Our study further contributes to the body of research through its employment of a training intervention to reduce interlimb asymmetry. The resulting outcome and interpretation may provide practitioners with evidence-based targets to implement in their work.

Therefore, the purposes of this study are to a) investigate the diagnostic utility of three different methods of classifying the meaningfulness of interlimb asymmetry, b) highlight the effects of a training intervention on interlimb asymmetry within the BSS exercise, c) determine whether a training intervention, purposed to decrease asymmetry, is warranted when the goal is to improve CoD performance.

It was hypothesized that participants within our study would fall into different categories of interlimb asymmetry, based on the method of classification. Further it was hypothesized that our training intervention would be capable of decreasing the magnitude of interlimb asymmetry within our sample. Lastly, it was hypothesized that decreases in interlimb asymmetry would subsequently lead to meaningful improvements within the respective CoD tests.

METHODS

Across a 6-week period, participants consisting of skill position players (i.e. wide-receiver, running back, defensive back) on the roster of a NCAA division 2 football team took part in a pre-, and post-testing session, as well as a 6-week training intervention. Each procedure is highlighted in more detail within the respective section below. All study procedures were approved by the University Institutional Review Board in accordance with the Declaration of Helsinki. Further, this research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (25).

Participants

The group of participants for this study initially consisted of 23 college aged skill position American football players (age = 21.2 ± 1.4 years, weight = 85.9 ± 6.2 kg, height = 183 ± 4.0 cm). All eligible participants had the opportunity to take as much time as desired to review the risks, ask questions, and receive an answer prior to signing the informed consent, and beginning study procedures. To be eligible to participate in this study, participants had to be an active participant on the roster of the University football team. They may not have suffered from any acute illness or musculoskeletal injuries that might have negatively affected their physical performance. Twenty-three participants completed all pre-testing procedures. A total of 20 participants completed all pre-testing procedures, the training intervention, and the post-intervention asymmetry tests. Loss of participants was the result of one subject experienced a roster change, one subject quitting the team two weeks into the training intervention, and one subject sustaining a non-study-related lower body injury during week 6 of the training intervention and choosing to not take part in post-testing procedures. Two participants sustained non-study-related upper-body injuries and were told by the sports medicine staff to not engage in the CoD post-testing procedures. However, these two participants did complete the lower-body part of the training intervention, as well as asymmetry post-testing procedures. Thus, a total of 18 participants completed all study-related procedures.

Protocol
Height was measured via a Seca stadiometer (Seca®, Chino, CA) and recorded in centimeters (cm). Bodyweight was measured using an electronic Befour PS 7700 scale (Befour®, Saukville, WI) and recorded in kilograms (kg). Weight measurements were rounded to the nearest 0.1 kg.

Pre- and post-testing was held within a weight room as well as on a turf field and consisted of the participants performing three sets of three repetitions within the Bulgarian Split Squat (BSS) exercise, followed by the performance of three attempts in the L-drill. These procedures were based on the findings by Philipp et al. who showed a link between the interlimb asymmetry within the BSS exercise and performance within the L-drill (29). A dynamic warm-up, led by a certified strength and conditioning coach was provided to all study participants prior to the commencement of the three working sets.

According to Helme et al. the BSS is a valid and reliable method for finding interlimb asymmetry (16). The procedures for testing asymmetry within the BSS exercise were adapted from McCurdy et al. (24), as well as Lockie et al. (21). However, rather than working up to a maximal set, participants were asked to perform three sets of three repetitions at a given load. For this study, it was estimated that the participants one-repetition maximum (1 RM) for the BSS was equal to 50% of their bilateral back squat 1 RM (17). Participants were asked to perform the BSS, using 85% of their estimated BSS 1RM. The participants estimated bilateral back squat 1RM was acquired during the first week of the offseason (1 week prior to pre-testing), by having the entire team engage in a 5RM testing session. This set and repetition scheme was to account for the balance issues experienced when working up to large loads within the BSS exercise, as highlighted by Philipp et al. (29), and for researchers to be able to calculate the CV for later sets and repetitions.

Following a dynamic warm up procedure, led by a certified strength and conditioning specialist, participants were assigned to one of two power racks for testing. Within the power rack, participants performed the BSS exercise, using a safety squat bar, with their hands placed on the safety handles in front of their body. The participants' rear foot was placed on a foam roller that was positioned on a 12-inch box. For safety, spotters were positioned on each side of the safety squat bar, and like recommendations by McCurdy et al. a successful repetition caused the femur of the working leg to be parallel to the floor, prior to the commencement of the concentric phase of the exercise (24). Participants were asked to perform the concentric phase of the exercise as explosively as possible.

Velocity and power applied to the safety squat bar were measured using a Tendo® unit linear position transducer (Tendo Sports Machines, Trencin, Slovakia), which was attached to the side of bar. The Tendo® unit provided researchers with a digital readout, from which peak velocity (PV), as well as average velocity (AV) were recorded for each limb. Computations for PV, and AV were calculated based on proprietary algorithms, while peak power (PP), and average power (AP) were manually calculated through the following calculation: "(load (kg) x velocity (m/s)) x 9.81". Interlimb asymmetry was calculated using the following calculation: "(Strong Limb – Weak Limb) / (Strong Limb) x 100", as suggested by Bishop et al. (6).

Participants performed three attempts of the L-drill (29). The total distance covered was 30 yards, and the three cones were placed 5 yards apart. An average of the three attempts was used for data analysis. A successful attempt required the participants to perform the test from start to finish without contacting any cone. Completion times were digitally recorded using one pair of Brower® timing gates (Brower Timing Systems, Draper, USA). Participants started the test in a three-point position with their hand placed 30 cm behind the timing gate. Participants broke the gate twice, once to start the drill and once to finish.

The procedures for the 505 CoD assessment was adapted from Nimphius et al. and involved the athletes starting in a two-point stance, linearly accelerating for 15 yards (13.7 meters), breaking a set of Brower® timing gates (Brower Timing Systems, Draper, USA) at the 10-yard (9.1 meter) line, planting their foot on the 15-yard line, and sprinting back through the gate at the 10-yard line (26). A researcher ensured that participants contacted the 15-yard line. Participants were given three attempts, with the mean of those three attempts being used for data analysis. Further, participants could choose which side to turn off.

For the sake of this investigation, asymmetry scores were classified in three different ways, following suggestions by Bishop et al. (1), as well as Dos'Santos et al. (14), who offered two concepts.

Classification 1: In a recent paper, Bishop investigated whether asymmetry thresholds are a usable concept, and proposed that rather than using arbitrary thresholds, practitioners should make use of a within-participants coefficient of variation (CV), accounting for test variability and task dependency, when looking at asymmetry (1). Following the suggestions, we classified participants as asymmetrical if their asymmetry value from the BSS exercise exceeded the CV, and symmetrical if their asymmetry value was below the CV.

Classification 2&3: Dos'Santos et al. recently proposed two methods for classifying interlimb asymmetry, trying to account for the task-dependent nature of interlimb asymmetry (14). The first is based on the population mean and smallest worthwhile change for a given asymmetry test. Participants were classified as having small to moderate asymmetries whenever their asymmetry value exceeded the population mean plus the smallest worthwhile change (SWC/0.2 x between-subject standard deviation). The second is based on the population mean and standard deviation. Participants were classified as having high or extreme levels of asymmetry whenever their asymmetry values exceeded the population mean plus the between-subject standard deviation.

Training Intervention: The training intervention consisted of 18 total training sessions, with three sessions each week over the course of 6 weeks. The training program was designed by the primary investigator in collaboration with the head strength and conditioning coach at UCM. Individual training sessions consisted of a mixture between unilateral and bilateral strength as well as plyometric exercises. Earlier investigations within this field of study have compared training interventions that either only consisted of unilateral or only bilateral exercises. Such training programs do not align with current strength and conditioning practices in which a mixture of bilateral and unilateral exercises is commonly implemented. Our training intervention aligns more with such practices and therefore adds to the body of literature. The 6-week training intervention consisted of two, 3-week phases. Athletes participated in other team activities, such as sport practices, during this time. A figure that contains the specific training intervention can be viewed as a supplementary file.

Statistical Analysis

All data were assessed for normality using a Shapiro-Wilk statistic. Further, data were screened for influential outliers (step of 1.5 x interquartile range) prior to conducting inferential tests. We used linear mixed models to investigate mean differences in primary study outcomes (i.e., interlimb asymmetry, L-drill and 505 performance) across fixed factors of time and asymmetry classification method, using the individual (ID) as a random factor. All post-hoc comparisons were adjusted using the Bonferroni correction. We used generalized linear models to investigate the probability of categorical change (i.e., improvement, regression) for all primary study outcomes across each asymmetry metric (i.e., Rel.AP vs. Rel.PP) and classification methods. Odds ratios (OR) for estimating the likelihood of improvement and regression in interlimb asymmetries for each classification method were calculated by the following equation: prob. asymmetrical group / prob. symmetrical group. Pearson's correlation coefficient was used to look at correlations between asymmetry change scores and CoD change scores and to figure out if the magnitude in reduction of asymmetry was related to the magnitude of improvement in CoD performance. All data are presented as means (M) ± standard deviations (SD). The reliability of asymmetry data was investigated using a CV, and data were considered reliable if the CV was below 10%. Data were analyzed using the R statistical computing environment and language (v. 4.0; R Core Team, 2020) via the Jamovi graphical user interface.

RESULTS

The mean load lifted in the BSS test was 90.7 ± 10.3 kg at pre-testing, and 97.0 ± 9.1 kg at post-testing. Reliability for individual relative power metrics, from which asymmetry scores were calculated were deemed acceptable, with a mean CV percentages under 10% for all metrics (Rel.AP CV% = 6.89 ± 2.20 at pre-testing, and 5.32 ± 1.35 at post-testing, Rel.PP CV% = 6.72 ± 1.74 at pre-testing, and 5.55 ± 1.65 at post-testing).As expected, participants within our study fell into different categories of interlimb asymmetry (asymmetrical vs. symmetrical), based on the method of interpretation, as well as the metric used to define interlimb asymmetry (Rel.AP and Rel.PP). Descriptive frequency statistics for asymmetry classification methods can be found in table 1.

Table 1. Asymmetry Classification Frequencies Based on Relative Average Power and Relative Peak Power

Classification Method		Rel. AP (W/kg)		Rel.PP (W/kg)	
		Pre	Post	Pre	Post
CV%	S	11	15	14	16
	As	9	5	6	4
M + SWC	S	9	17	12	17
	AS	11	3	8	3
M + SD	S	16	20	15	20
	AS	4	0	5	0

Note. S = Symmetrical, AS = Asymmetrical, Rel.AP (W/kg) = Relative Average Power, Rel.PP (W/kg) = Relative Peak Power, CV = Coefficient of Variation, SWC = Smallest Worthwhile Change, M = Mean

Tables 2 & 3 show mean completion time differences within respective CoD tests, across time and asymmetry classification methods for Rel.AP and Rel.PP

Table 2. L-drill mean completion time differences across time and asymmetry classification methods for Rel.AP and Rel. PP (W/kg)

		Pre	Post	Change	*p*-value	Cohen's *d*
	Rel.AP (W/kg)					
CV%	Symmetrical	7.05 ± 0.23	7.02 ± 0.21	-0.03	1.000	0.13
	Asymmetrical	7.06 ± 0.25	7.00 ± 0.32	-0.06	1.000	0.21
Group Aggregate		7.05 ± 0.17	7.01 ± 0.19	-0.04	0.412	0.22
M + SWC	Symmetrical	7.02 ± 0.25	7.02 ± 0.19	0.00	1.000	0.00
	Asymmetrical	7.08 ± 0.22	6.98 ± 0.41	-0.10	1.000	0.30
Group Aggregate		7.05 ± 0.17	7.00 ± 0.24	-0.05	0.414	0.24
M + SD	Symmetrical	7.02 ± 0.18	7.01 ± 0.17	-0.01	‡0.900	0.11
	Asymmetrical	7.13 ± 0.35	NA	NA	NA	NA
Group Aggregate		7.08 ± 0.19	NA	NA	NA	NA
Study Aggregate		7.05 ± 0.19	7.01 ± 0.14	-0.04	0.515	0.21

		Pre	Post	Change	*p*-value	Cohen's *d*
	Rel.PP (W/kg)					
CV%	Symmetrical	7.03 ± 0.21	7.03 ± 0.19	---	1.000	---
	Asymmetrical	7.09 ± 0.30	6.96 ± 0.36	-0.13	1.000	0.39
Group Aggregate		7.06 ± 0.18	6.99 ± 0.21	-0.07	0.233	0.36
M + SWC	Symmetrical	7.04 ± 0.22	7.02 ± 0.19	-0.02	1.000	0.10
	Asymmetrical	7.07 ± 0.26	6.99 ± 0.42	-0.08	1.000	0.23
Group Aggregate		7.05 ± 0.17	7.01 ± 0.23	0.04	0.419	0.20
M + SD	Symmetrical	7.01 ± 0.18	7.01 ± 0.17	-0.002	‡0.968	0.06
	Asymmetrical	7.14 ± 0.30	NA	NA	NA	NA
Group Aggregate		7.08 ± 0.19	NA	NA	NA	NA
Study Aggregate		7.05 ± 0.19	7.01 ± 0.14	-0.04	0.515	0.21

Note, ‡ = A student's t-test was used to derive this probability, Relative Average Power, Rel.PP (W/kg) = Relative Peak Power, CV = Coefficient of Variation, SWC = Smallest Worthwhile Change, M = Mean, NA = Not Applicable as no subject fell into this category.

Table 3. 505 mean completion time differences across time and asymmetry classification methods for Rel.AP and Rel. PP (W/kg)

		Pre	Post	Change	*p*-value	Cohen's *d*
	Rel.AP (W/kg)					
CV%	Symmetrical	1.96 ± 0.08	1.99 ± 0.08	+0.03	1.000	-0.38
	Asymmetrical	1.95 ± 0.10	2.00 ± 0.12	+0.05	0.732	-0.45
Group Aggregate		1.96 ± 0.05	2.00 ± 0.08	+0.04	0.070	-0.88
M + SWC	Symmetrical	1.97 ± 0.09	1.97 ± 0.06	---	1.000	---
	Asymmetrical	1.94 ± 0.08	2.10 ± 0.13	+0.16	<.001	-1.48
Group Aggregate		1.96 ± 0.06	2.04 ± 0.08	+0.08	<.001	-1.13
M + SD	Symmetrical	1.96 ± 0.06	1.99 ± 0.06	+0.03	‡0.080	-0.50
	Asymmetrical	1.93 ± 0.13	NA	NA	NA	NA
Group Aggregate		1.95 ± 0.08	NA	NA	NA	NA
Study Aggregate		1.96 ± 0.06	1.99 ± 0.06	+0.03	0.515	-0.61

		Pre	Post	Change	*p*-value	Cohen's *d*
	Rel.PP (W/kg)					
CV%	Symmetrical	1.95 ± 0.06	2.00 ± 0.06	+0.05	0.282	-0.83
	Asymmetrical	1.97 ± 0.11	1.97 ± 0.14	+0.00	1.000	0.00
Group Aggregate		1.96 ± 0.06	1.99 ± 0.08	+0.03	0.291	0.42
M + SWC	Symmetrical	1.97 ± 0.08	2.00 ± 0.06	+0.03	1.000	-0.42
	Asymmetrical	1.94 ± 0.09	1.96 ± 0.15	+0.02	1.000	-0.16
Group Aggregate		1.95 ± 0.06	1.98 ± 0.09	+0.03	0.279	0.39
M + SD	Symmetrical	1.96 ± 0.06	1.99 ± 0.06	+0.03	‡0.079	-0.50
	Asymmetrical	1.94 ± 0.13	NA	NA	NA	NA
Group Aggregate		1.95 ± 0.06	NA	NA	NA	NA
Study Aggregate		1.96 ± 0.06	1.99 ± 0.06	+0.03	0.515	-0.61

Note, ‡= A student's t-test was used to derive this probability, Relative Average Power, Rel.PP (W/kg) = Relative Peak Power, CV = Coefficient of Variation, SWC = Smallest Worthwhile Change, M = Mean, NA = Not Applicable as no subject fell into this category.

Probabilities for improvement or regression in interlimb asymmetry across different classification methods and metrics are shown in table 4. Participants classified as asymmetrical through the M + SD classification method had the greatest odds of meaningfully reducing interlimb asymmetry in Rel.AP (OR = 9.0, 95% CI: 2.8, 15.2) and Rel.PP (OR = 6.99, 95% CI: 1.4, 12.5) through participation in our intervention.

Table 4. Probabilities for improvement or regression in asymmetry (Rel.AP and Rel.PP), across classification methods

Asymmetry$_{\Delta}$		Rel. AP CV%	Rel. AP M + SWC	Rel. AP M + SD	Rel. PP CV%	Rel. PP M + SWC	Rel. PP M + SD
Probability of Improvement	AS	0.429 (9)	0.643 (11)	1.00 (3)	0.500 (6)	0.636 (8)	1.00 (5)
	S	0.231 (11)	0.346 (9)	0.111 (17)	0.167 (14)	0.241 (12)	0.143 (15)
Probability of Regression	AS	0.143 (9)	0.071 (11)	NA	0.300 (6)	0.182 (8)	NA
	S	0.027 (11)	0.039 (9)	NA	0.100 (14)	0.069 (12)	NA

Note. Data are presented probability (# of classified participants), AS = Asymmetrical, S = Symmetrical, Relative Average Power, Rel.PP (W/kg) = Relative Peak Power, CV = Coefficient of Variation, SWC = Smallest Worthwhile Change, M = Mean, NA = Not Applicable as no subject fell into this category.

Probabilities for improvement or regression in L-drill performance across different classification methods and metrics are shown in table 5. For L-drill performance, participants classified as asymmetrical through the M + SD classification method had the greatest odds of improving L-drill performance through engaging in our intervention. This was the case for both Rel.AP (OR = 1.33, 95% CI: -2.1, 4.8) and Rel.PP (OR = 1.33, 95% CI: -2.1, 4.8).

Table 5. Probabilities for improvement or regression in L-drill performance across classification methods

L-drill$_{\Delta}$		Rel. AP CV%	Rel. AP M + SWC	Rel. AP M + SD	Rel. PP CV%	Rel. PP M + SWC	Rel. PP M + SD
Probability of Improvement	AS	0.643 (9)	0.692 (10)	0.749 (3)	0.667 (6)	0.667 (7)	0.749 (4)
	S	0.545 (10)	0.522 (9)	0.562 (16)	0.555 (13)	0.555 (12)	0.562 (15)
Probability of Regression	AS	0.357 (9)	0.308 (10)	0.249 (3)	0.333 (6)	0.333 (7)	0.249 (4)
	S	0.318 (10)	0.348 (9)	0.343 (16)	0.333 (13)	0.333 (12)	0.343 (15)

Note. Data are presented probability (# of classified participants), AS = Asymmetrical, S = Symmetrical, Relative Average Power, Rel.PP (W/kg) = Relative Peak Power, CV = Coefficient of Variation, SWC = Smallest Worthwhile Change, M = Mean

Probabilities for improvement or regression in 505 performance across different classification methods and metrics are shown in table 6. Looking at the 505 CoD drill, participants classified as having Rel.AP asymmetries exceeding the CV% showed the greatest odds of improvement (OR = 0.78, 95% CI: -4.1, 5.7). Further, participants classified as having Rel.PP asymmetries exceeding the sample M + SD showed the greatest odds of improving 505 performance (OR = 0.73, 95% CI: -4.4, 5.9). Overall, looking at the 505 CoD drill, the odds of regression through participation in our intervention were greater than the odds of improvement.

Table 6. Probabilities for improvement or regression in 505 performance across classification methods

505 Change$_{\Delta}$		Rel. AP CV%	Rel. AP M + SWC	Rel. AP M + SD	Rel. PP CV%	Rel. PP M + SWC	Rel. PP M + SD
Probability of Improvement	AS	0.286 (9)	0.154 (10)	0.250 (3)	0.111 (6)	0.111 (7)	0.250 (4)
	S	0.364 (10)	0.435 (9)	0.344 (16)	0.407 (13)	0.407 (12)	0.344 (15)
Probability of Regression	AS	0.500 (9)	0.615 (10)	0.750 (3)	0.444 (6)	0.444 (7)	0.750 (4)
	S	0.409 (10)	0.348 (9)	0.406 (16)	0.444 (13)	0.444 (12)	0.406 (15)

Note. Data are presented probability (# of classified participants), AS = Asymmetrical, S = Symmetrical, Relative Average Power, Rel.PP (W/kg) = Relative Peak Power, CV = Coefficient of Variation, SWC = Smallest Worthwhile Change, M = Mean

At the group level, statistically significant reductions in Rel. AP and Rel.PP asymmetry from pre- to post-intervention were paralleled by positive changes in L-drill performance that exceeded the SWC and CV% (0.2 x sample standard deviation). Descriptive statistics for pre-, to post-intervention comparisons with regards to Rel.AP and Rel.PP can be found in table 7. These results have been further broken down by classification methods, for a comparison in asymmetry change based on the respective means of classifying asymmetry. Table 9 presents aggregate data on changes in Rel.AP asymmetry over time grouped by classification method and baseline classification (i.e., symmetrical vs. asymmetrical), while table 10 does the same for Rel.PP asymmetry.

Table 7. Rel.AP & Rel.PP (W/kg) Asymmetry differences across time and asymmetry classification methods

		Pre	Post	Change	*p*-value	Cohen's *d*
	Rel.AP (W/kg)					
CV%	Symmetrical	3.00 ± 1.3	2.24 ± 1.1	-0.76	1.00	0.63
	Asymmetrical	8.84 ± 1.4	6.41 ± 1.9	-2.43	0.356	1.46
Group Aggregate		5.92 ± 2.2	4.32 ± 2.5	-1.60	0.036	0.68
M + SWC	Symmetrical	1.92 ± 1.2	2.58 ± 0.9	+0.66	1.00	0.34
	Asymmetrical	8.66 ± 1.1	7.24 ± 2.1	-1.42	1.00	0.85
Group Aggregate		5.29 ± 1.9	4.91 ± 2.6	0.38	0.590	0.17
M + SD	Symmetrical	4.43 ± 1.4	3.28 ± 1.2	-1.15	‡0.054	0.88
	Asymmetrical	10.24 ± 2.7	NA	NA	NA	NA
Group Aggregate		7.43 ± 3.4	NA	NA	NA	NA
Study Aggregate		5.63 ± 3.9	3.28 ± 2.4	-2.35	0.027	0.73

		Pre	Post	Change	*p*-value	Cohen's *d*
	Rel.PP (W/kg)					
CV%	Symmetrical	2.79 ± 1.0	1.63 ± 0.9	-1.16	0.582	1.13
	Asymmetrical	8.33 ± 1.5	6.17 ± 1.8	-2.16	0.544	1.30
Group Aggregate		5.56 ± 2.1	3.90 ± 2.4	-1.66	0.023	0.74
M + SWC	Symmetrical	2.08 ± 0.9	1.82 ± 0.7	+0.36	1.00	-0.32
	Asymmetrical	8.01 ± 1.1	6.62 ± 1.8	-1.42	1.00	0.93
Group Aggregate		5.05 ± 1.7	4.22 ± 2.3	-0.83	0.192	0.41
M + SD	Symmetrical	2.85 ± 1.1	2.54 ± 0.9	-0.31	‡0.674	0.31
	Asymmetrical	9.26 ± 1.8	NA	NA	NA	NA
Group Aggregate		6.06 ± 1.06	NA	NA	NA	NA
Study Aggregate		4.45 ± 3.4	2.54 ± 2.2	-1.91	0.065	0.67

Note, ‡ = A student's t-test was used to derive this probability, Relative Average Power, Rel.PP (W/kg) = Relative Peak Power, CV = Coefficient of Variation, SWC = Smallest Worthwhile Change, M = Mean, NA = Not Applicable as no subject fell into this category.

At the individual level however, the degree of reduction in asymmetry across the training intervention did not seem to align with improvements in CoD performance. Pre- to Post-intervention asymmetry change scores (subscript$_{\Delta}$) for both asymmetry metrics only showed small, non-significant correlations with change scores (subscript$_{\Delta}$) in CoD performance (table 8 and 9).

Table 8. Correlation Matrix for L-drill change vs. asymmetry change

		L-drill$_{\Delta}$	Rel. AP Asymmetry$_{\Delta}$
L-drill$_{\Delta}$	Pearson's *r*	-	
	p-value	-	
Rel. AP Asymmetry$_{\Delta}$	Pearson's *r*	0.053	-
	p-value	0.761	-
Rel. PP Asymmetry$_{\Delta}$	Pearson's *r*	0.103	0.626
	p-values	0.551	< .001

Table 9. Correlation Matrix for 505 change vs. asymmetry change

		505$_{\Delta}$	Rel. AP Asymmetry$_{\Delta}$
505$_{\Delta}$	Pearson's *r*	-	
	p-value	-	
Rel. AP Asymmetry$_{\Delta}$	Pearson's *r*	0.099	-
	p-value	0.688	-
Rel. PP Asymmetry$_{\Delta}$	Pearson's *r*	0.145	0.883
	p-values	0.553	< .001

DISCUSSION

This study sought to answer three primary aims. Aim one was to evaluate the diagnostic utility of three different methods of asymmetry classification. Aim two was to find whether a 6-week training intervention was able to meaningfully decrease the magnitude of interlimb asymmetry for Rel.AP and Rel.PP. Lastly, aim three was to determine if there was a relationship between changes in asymmetry and changes in CoD performance. Study hypotheses included that participants would differ in their baseline classification (i.e., asymmetrical vs. symmetrical) based on the method of classification employed, that the training intervention would meaningfully reduce interlimb asymmetries, and that decreases in asymmetry would directly relate to improvements in CoD performance.

In accordance with study aim 1 and the related hypothesis, results from this study show that participants indeed fell into different baseline classification categories based on the method used. More participants were classified as asymmetrical using the CV% and M + SWC methods, while less participants were classified as asymmetrical using the M + SD method (see table 1). The M + SD method was suggested by Dos'Santos et al. to classify athletes experiencing high or extreme levels of asymmetry (14).

Investigating the diagnostic utility of each asymmetry classification method employed consisted of estimating the probabilities for improvement or regression of CoD performance associated with participants baseline classification category (i.e., asymmetrical vs. symmetrical). OR's were calculated to find potential asymmetry metrics in which optimal outcomes (i.e., maximized likelihood of improvement of CoD performance) were observed. Participants classified as asymmetrical via the M + SD method had the greatest odds of improving asymmetry because of the training intervention. This seems logical since this group of participants had the largest observed magnitudes in baseline asymmetry scores. Thus, these athletes had the largest room for improvement according to this method of asymmetry classification. Conversely, athletes classified as asymmetrical via the CV% method had the greatest odds of regression (i.e., increasing asymmetry) from baseline assessment. It seems clear that the M + SD classification method may be a more conservative method that allows practitioners to intervene in only the athletes who will benefit from a training intervention designed to reduce interlimb asymmetries. This finding is in line with suggestions by Dos'Santos et al. who suggested that this approach will classify a smaller proportion (~16%) of athletes within a sample (14).

With respect to changes in L-drill and 505 performance, we again used the estimated probabilities of improvement or regression with respect to baseline classification to evaluate the diagnostic utility of each asymmetry classification method. Mirroring the improvements in asymmetry, participants classified as asymmetrical via the M + SD method, had the greatest odds of improvement in CoD performance (assessed via the L-drill test) following the training intervention. These findings are encouraging as, taken together, they supply confirmatory evidence to suggest that using the M + SD method of asymmetry classification could allow practitioners to intervene only in those athletes who are most likely to directly benefit from asymmetry reduction. This is particularly important when one considers that reducing asymmetry does not automatically result in performance enhancement for an individual; evidenced by the likelihood of regression in CoD performance within the CV% and M + SWC methods and the non-existent correlations between changes in asymmetry and changes in CoD performance.

Furthermore, with use of the M + SD method, one can recommend the assessment of the Rel.PP metric of asymmetry as the primary measure of interest used to classify athletes. The rationale for this assertion is that (using this metric) five athletes were classified as asymmetrical, while only three athletes were classified as asymmetrical using the Rel.AP metric. Capturing the highest number of athletes who will benefit optimally from training interventions should be a priority for practitioners. In addition, most velocity assessment devices simultaneously record peak and average power, so this is simple to implement and is a practical distinction to make.

Interestingly, unlike the findings from asymmetry and L-drill performance, the results for the 505 drill are chaotic. Principle among this chaos is the fact that 505 performances actually decreased across the entire sample which is further compounded by probabilities of regression in performance actually being greater than the likelihood of improvement for all classification methods. It is difficult to ascertain the reason behind this finding. Future studies may elect to choose procedures that involve the athletes having to turn off each side, allowing researchers to investigate changes for both sides, as well as a potential CoD performance "asymmetries." The previously highlighted findings agree with ideas by Philipp et al. who suggested that the L-drill might be more sensitive towards identifying or highlighting interlimb asymmetries (29).

With respect to the second study aim, we observed significant changes in interlimb asymmetries following the 6-week training intervention. Looking across the entire sample, the training intervention was able to meaningfully reduce the level of asymmetry within our participants. Further, these decreases in asymmetry were paralleled by an improvement in L-drill performance that exceeded our SWC across the entire sample, while a decrease in 505 drill performance was observed. As hypothesized, our data showed significant main effects for time, specifically looking at the reduction in asymmetry from pre- to post-intervention, across as classification methods. While the training intervention used within our study poses an example for a training program which practitioners may use to correct any existing interlimb asymmetries, there are a few thoughts and avenues future research might investigate. As an example, future research might look at specific time-courses for eliciting desired levels in asymmetry reduction.

Lastly, as aim three, this study looked to further expand on the potential relationship between interlimb asymmetry and CoD performance. Specifically, it looked to address the limitations in earlier cross-sectional, descriptive studies by investigating the potential causality of this relationship. To do this, change scores in both asymmetry and CoD performance (i.e., L-drill) were used as primary variables of interest.

Across the entire sample, no significant relationship between the change in asymmetry and the change in CoD performance is observed. However, given that asymmetry is highly dependent on the task and metric used to estimate it and the directionality in response (i.e., improvement or regression) in CoD performance varied considerably, delimiting these data to only include participants for whom the best responses were observed (i.e., reduction in asymmetry and improvement CoD performance) is logical. This contention is grounded in the reality that, in practice, our goal would only be to intervene and expect a direct relationship between these variables in the "correct" subset of athletes.

This study is not without limitations. One primary limitation might be the overall low magnitude of asymmetry observed in this sample. Future research might use our methodological approach within a sample that exhibits a wider range of interlimb asymmetry levels, for instance athletes with less experience in resistance training, or athletes from sports in which larger degrees of asymmetry might be expected, such as cricket (10). Further, five athletes were not able to complete all study-related procedures due to non-study related reasons. While our sample size was sufficient for most team-sport populations, future research may focus on similar analyses in larger samples. Lastly, the load used for the performance of the BSS might only have provided a submaximal stimulus and failed to load the respective limbs maximally. Future research might reevaluate methodologies to maximally stress limbs with loads that are closer to the subjects 1RM.

This study demonstrates that interlimb asymmetry is specific to the method of asymmetry classification. We suggest practitioners classify and intervene in only those athletes whose asymmetry scores exceed the sample M + SD using the Rel.PP metric. Although Rel.AP seems to be a more stable and reliable metric, we recommend use of the Rel.PP metric due to its' specificity for identifying potential athletes that could benefit from a training intervention targeted to reduce asymmetry. Further, these data also demonstrated acceptable reliability. This strategy represents a sensitive approach to asymmetry identification while maximizing the specificity of the test. These results should be of interest to practitioners who implement training interventions aimed at reducing the level of asymmetry to increase CoD performance. While we have suggested the use of specific asymmetry classification methods as a guide within our study, we encourage practitioners to recreate methodological approaches highlighted within our study and apply them to their own set of athletes. Interlimb asymmetry is still a highly task- and metric-specific phenomenon that requires an individualized approach.

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