

The Ecological Validity of Countermovement Jump to On-Court Asymmetry in Basketball



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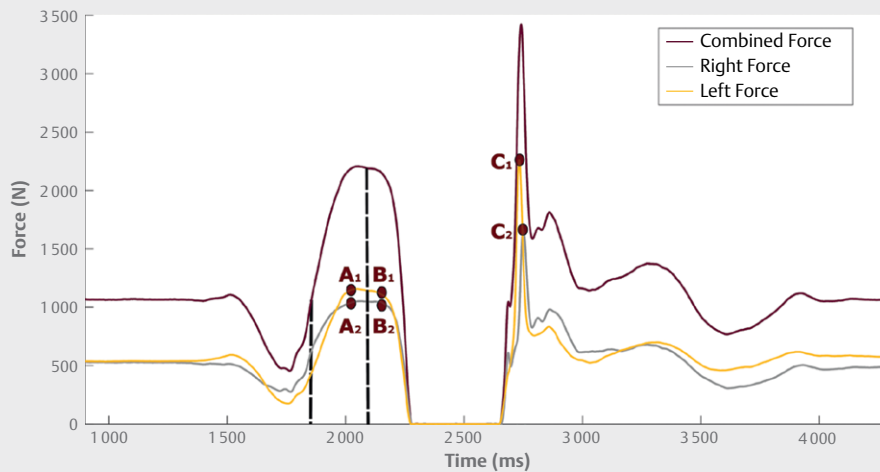
ABSTRACT

Jump-based asymmetry is often used as an indicator of sport performance and may be used to discern injury susceptibility. Due to task specificity, however, countermovement jump asymmetry may not be representative of on-court asymmetry. As such, we assessed the association between countermovement jump asymmetry and on-court impact asymmetry metrics ($n = 3$, and $n = 4$, respectively) using linear regressions ($\alpha = 0.05$). Fifteen female basketball athletes completed countermovement jump and on-court sessions across a competitive season. A significant negative association was found between peak landing force asymmetry and both overall and medium acceleration on-court asymmetry ($b = -0.1$, $R^2 = 0.08$, $p < 0.001$; $b = -0.1$, $R^2 = 0.11$, $p < 0.001$, respectively), as well as between peak propulsive force asymmetry and on-court medium acceleration asymmetry ($b = -0.24$, $R^2 = 0.04$, $p = 0.01$). Alternatively, both peak landing and peak propulsive force asymmetry were significantly positively associated with on-court high acceleration asymmetry ($b = 0.17$, $R^2 = 0.08$, $p < 0.001$; $b = 0.35$, $R^2 = 0.02$, $p = 0.04$, respectively). While some overlap may exist, countermovement jump and on-court impact asymmetry appear to be independent. Thus, sport-specific monitoring may be necessary to adequately monitor injury susceptibility using asymmetry.

Introduction

Countermovement jump (CMJ) testing is a widely used tool to monitor athletic training [1–3]. When integrated with force plates, CMJ testing can provide detailed and reliable information on an athlete's ability to produce force and power (e. g., peak force, peak power, rate of force development, and impulse) across the movement phases of the CMJ [2, 4–9]. Moreover, with the use of bilateral force plates, CMJ testing may offer the opportunity to identify between-limb differences that exist during jump performance. Inter-limb asymmetry has

been used extensively in rehabilitative settings to help athletes to successfully return to sport and may provide a marker of injury susceptibility, although the extent to which jump asymmetries relate to risk of injury is equivocal [10–17]. Furthermore, lower-extremity injury is often multifactorial [18–22], and thus it is difficult to determine injury susceptibility and ultimately flag potential impending injuries using a univariate measure such as asymmetry obtained from CMJ testing and associated force plate analyses.



► **Fig. 1** Countermovement jump force-time waveform for three inter-limb difference metrics: a) peak braking force asymmetry (PBFA), b) peak propulsive force asymmetry (PPFA), and c) peak landing force asymmetry (PLFA). The dashed lines represent the beginning and end of the propulsive phase of the countermovement jump, while left and right limb forces for each inter-limb asymmetry metric are denoted with numbers 1 and 2, respectively.

Unfortunately, the association of these CMJ asymmetries with more realistic on-court movements has been debated [7, 23, 24]. Research has shown that asymmetry can be task-specific, meaning asymmetries observed during CMJs may not be truly predictive of the asymmetries seen in more game- or sport-specific situations [25–27]. More specifically, inter-limb asymmetry has been demonstrated to be highly variant based upon the participating muscle groups, whether the task completed is a unilateral or bilateral exercise, and the outcome measure of interest (e. g., maximal velocity for rate of torque development vs. maximal torque output) [25, 26].

Fortunately, wearable technology has enhanced our ability to reliably track human movement in real-world settings [28–32]. Wearable technology is used extensively in running to measure spatiotemporal, kinetic, and kinematic variables, and this methodology has proven to be viable to analyze gait variability and potential indicators of pathology [28, 29]. However, this application has been lacking for more dynamic team sports such as basketball, which has one of the highest injury incidences of all collegiate sports [33, 34]. This lack of on-court basketball assessment is even more problematic for female basketball athletes [29, 35, 36], as this population has historically been more prone to sustaining severe lower-extremity injuries [18, 19, 37–41]. Therefore, given the potential association of inter-limb asymmetry to injury susceptibility, and the necessity to better monitor female basketball athletes in sport-specific settings where such injuries are sustained, there is an urgent need to ascertain whether asymmetry as determined by CMJ testing is related to what is seen on court.

Objectives

The aim of the present study was to examine the ecological validity of inter-limb asymmetry metrics obtained from CMJ testing on a dual force platform in relation to the on-court impact asymmetry obtained via inertial measurement units in collegiate female bas-

ketball athletes. Given that wearable sensors can assess the impacts experienced by the lower limbs, we hypothesized that the CMJ landing asymmetry would yield the highest validity to those taken on court by the wearable sensors.

Materials and Methods

Study design

A repeated-measures design with an 8-month study period (i. e., an entire competitive collegiate basketball season) was utilized to determine the association of CMJ asymmetry to on-court asymmetry in female varsity basketball athletes. CMJ testing was performed weekly on Monday mornings after a dynamic warm-up and prior to any form of fatiguing exercise that would perturb jumping performance. Three on-court wearable inertial sensor data collections were conducted on the same day each week (Tuesday, Wednesday, and Friday) during normatively scheduled basketball practices. Weekly asymmetry scores were computed as the average from the three weekly practice sessions. From the CMJ testing, three peak force asymmetry metrics (one pertaining to each of the braking, propulsive, and landing phases of movement) were obtained via dual force platforms and used as the independent variables (IVs) in this study. Additionally, four impact asymmetry metrics (overall impact asymmetry, as well as impact asymmetry stratified into low, medium, and high intensity bins) obtained from the wearable inertial sensors were used as the dependent variables (DVVs). Inter-limb asymmetry was measured due to its relation to injury susceptibility and sport performance [10, 42–45].

Subjects

Fifteen female collegiate basketball athletes (guards: $n = 8$, forwards: $n = 4$, and centers: $n = 3$) volunteered to participate in the study: age 20 ± 2 years, height 180 ± 9 cm, mass 73 ± 11 kg, coun-

termovement jump height 0.23 ± 0.05 m, and training experience 3 ± 1 years. All participants were free of any musculoskeletal injury that would hamper their ability to fully participate, and they were informed of the potential risks, benefits, and study protocol and made fully aware of their ability to withdraw from the study at any time prior to commencement. Written consent was obtained from all athletes who participated in this study. This study was reviewed and approved by the university research ethics board and the coaching staff of the basketball team.

Procedures

A 5-minute standardized dynamic warm-up was completed prior to CMJ testing to sufficiently prepare the neuromuscular system for the demands of maximal effort jumping. CMJs were performed on a dual force plate system (Hawkin Dynamics, Westbrook, ME, USA) with a sampling frequency of 1000 Hz. Participants performed three maximal effort CMJ attempts with a minimum of 60 seconds of rest between successive attempts. Strong verbal cues and encouragement were provided to participants by strength and conditioning staff as they performed each jump with hands placed on hips and a self-selected countermovement depth. As stated above,

► **Table 1** Descriptive statistics for both countermovement jump and on-court asymmetry metrics obtained across an eight-month competitive collegiate basketball season across all female athletes.

Countermovement jump asymmetry metrics	Mean (SD)
Peak braking force asymmetry (%)	-1.57 (7.24)
Peak propulsive force asymmetry (%)	-0.98 (4.19)
Peak landing force asymmetry (%)	-1.79 (15.56)
On-court asymmetry metrics	Mean (SD)
Overall impact asymmetry (%)	0.51 (5.54)
Low impact (1–5 g) asymmetry (%)	0.01 (2.81)
Medium impact (6–20 g) asymmetry (%)	-0.10 (4.80)
High impact (21–200+ g) asymmetry (%)	-0.85 (9.26)

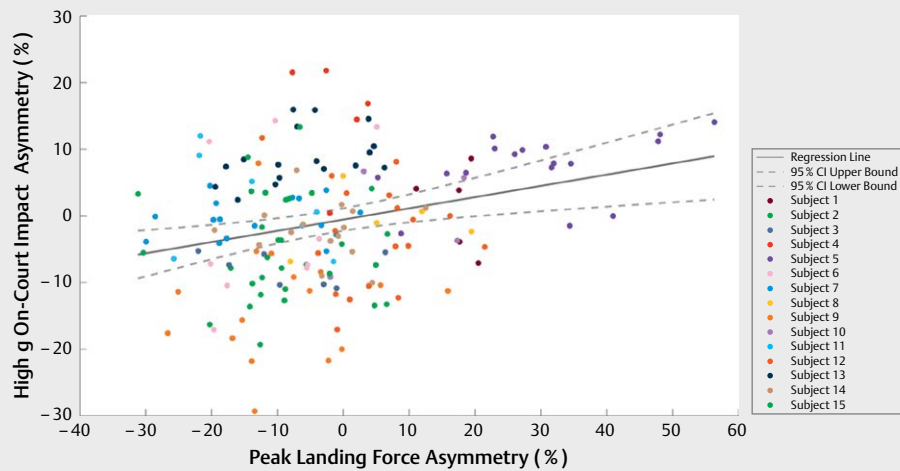
three peak force asymmetry metrics (i. e., peak braking force, peak propulsive force, and peak landing force asymmetry) were obtained from the CMJs via the dual force plate proprietary software (Hawkin Dynamics). Specifically, the average between-limb difference observed for each of these peak force asymmetry metrics across the three CMJ attempts completed at each weekly testing session was recorded and utilized for regression analyses. A visual representation of these three CMJ peak force asymmetry metrics can be found in ► **Fig. 1**.

Prior to on-court sessions, participants were fitted with two inertial measurement units (IMeasureU Inc., IMU Step, Denver, CO, USA), which were positioned bilaterally anterosuperior to the medial malleoli using semi-elastic straps. Given that these wearable sensors were worn bilaterally, we were able to collect overall impact asymmetry data, as well as impact asymmetry stratified into low, medium, and high intensity bins (1–5 g, 6–20 g, and 21–200+ g, respectively) [32] throughout 90- to 120-minute on-court basketball training sessions. Specifically, these four on-court impact acceleration asymmetry metrics were the average between-limb differences calculated across the entire on-court basketball training session (i. e., overall impact acceleration asymmetry), along with the average sessional between-limb differences calculated in the aforementioned intensity bins. CMJ testing was completed once per week, while on-court sessions were completed three times per week across the entire 2021–2022 collegiate basketball competitive season (i. e., eight months), which consisted of one month of off-season training, two months of pre-season training, and five months of in-season competition. All IVs were computed from ground reaction force data, while DVs were computed using resultant accelerometer data, all of which were obtained from the respective manufacturer-provided software, which has been demonstrated to be reliable and valid as compared to gold standards [32, 46].

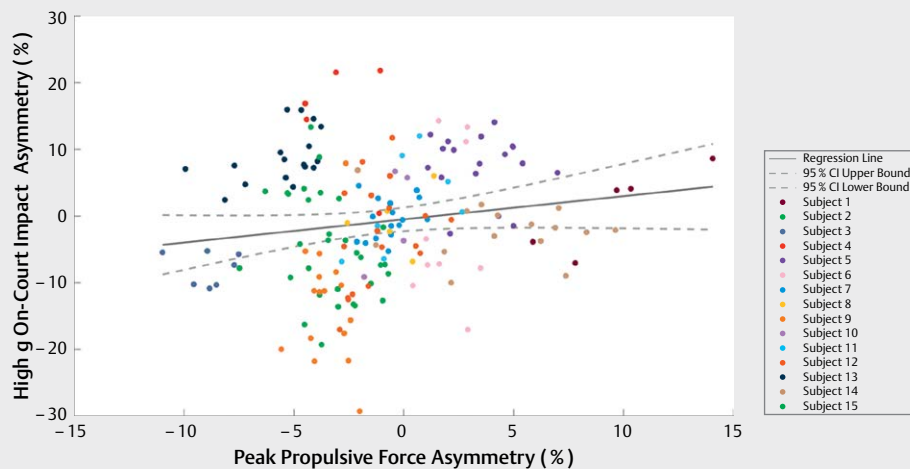
► **Table 2** Association between countermovement jump and on-court asymmetry metrics.

Relationships between CMJ and on-court asymmetry metrics					
		b (95% CI)	R ²	Estimate of error variance	p-value
Overall impact asym.	PBFA	-0.03 (-0.15, 0.08)	0	30.84	0.6
	PPFA	-0.17 (-0.36, 0.03)	0.02	30.40	0.1
	PLFA	-0.10 (-0.15, -0.05)	0.08	28.45	<0.001
Low impact (1–5 g) asym.	PBFA	-0.02 (-0.07, 0.04)	0	7.92	0.59
	PPFA	-0.04 (-0.14, 0.06)	0	7.9	0.41
	PLFA	-0.02 (-0.05, 0)	0.02	7.8	0.09
Medium impact (6–20 g) asym.	PBFA	-0.04 (-0.14, 0.06)	0	23.08	0.4
	PPFA	-0.24 (-0.41, -0.07)	0.04	22.18	0.01
	PLFA	-0.10 (-0.15, -0.06)	0.11	20.6	<0.001
High impact (21–200+ g) asym.	PBFA	0.07 (-0.12, 0.26)	0	85.99	0.49
	PPFA	0.35 (0.02, 0.68)	0.02	84.08	0.04
	PLFA	0.17 (0.08, 0.25)	0.08	79.32	<0.001

Abbreviations: CMJ, countermovement jump; PBFA, peak braking force asymmetry; PPFA, peak propulsive force asymmetry; PLFA, peak landing force asymmetry; asym., asymmetry.



► **Fig. 2** Correlation of weekly observations for CMJ PLFA vs. on-court high acceleration impact asymmetry for all 15 subjects across an eight-month competitive season.



► **Fig. 3** Correlation of weekly observations for CMJ PPFA vs. on-court high acceleration impact asymmetry for all 15 subjects across an eight-month competitive season.

Statistical analyses

Weekly CMJ asymmetry scores for the three IVs were computed as the average for the three jumps performed on a given weekly testing session, as this approach has been noted to improve the reliability of CMJ asymmetry metrics [27]. Further, weekly on-court asymmetry scores were computed as the average value of the three sessional asymmetry scores in each week. Weekly observation data were included for analysis if participants completed both CMJ testing and on-court sessions, otherwise the data were removed. A total of 173 synonymous weekly observations were obtained across the competitive collegiate season. To address the research question, multiple univariate regression analyses were computed with coefficient estimates and 95% confidence intervals at an alpha level of 0.05 to assess the association between the three IVs to the four DVs.

Results

Regression analyses

Descriptive statistics across the eight-month study period across all 15 female collegiate basketball athletes, including the mean and standard deviation for all CMJ and on-court asymmetry metrics, are presented in ► **Table 1**. The results for the univariate regression analyses are presented in ► **Table 2**. It was found that both peak landing force asymmetry (PLFA) and peak propulsive force asymmetry (PPFA) were significantly positively associated with high acceleration impact asymmetry observed on court ($p = 1.6 \times 10^{-4}$ and $p = 0.04$, respectively). However, these same CMJ asymmetry metrics were significantly negatively associated with medium acceleration impact asymmetry observed on court ($p = 7.2 \times 10^{-6}$ and

$p=0.01$, respectively), while PLFA was also significantly negatively associated with overall on-court impact asymmetry ($p=1.8 \times 10^{-4}$). These contrary findings make sense as they appear at different binned impact accelerations observed on court. More specifically, as CMJ asymmetry increases, so does on-court asymmetry during more ballistic movements. However, this is compensated by the contralateral limb during more moderate impact acceleration movements (e. g., jogging to running) in an inherent preservative manner to offload musculoskeletal structures and to avoid overuse. Visual representations of the significant positive associations found between CMJ PLFA and PPFA vs. on-court high acceleration impact asymmetry can be found in ► **Fig. 2** and ► **Fig. 3**, respectively.

Discussion

This study aimed to discern the ecological validity of force plate-derived inter-limb asymmetry metrics relative to impact asymmetry metrics seen on court in female collegiate basketball athletes. In accordance with our hypothesis, CMJ PLFA was significantly positively associated with on-court impact asymmetry, particularly during more ballistic movements. However, the R^2 values suggest that while these modalities may be associated with one another, it appears that these asymmetry measures are relatively unique and independent of one another.

The lack of a strong association between inter-limb asymmetry displayed during CMJ testing compared to the impact asymmetry seen on court in basketball athletes is not surprising given the often task-specific nature of asymmetry [25–27]. The presence of limb dominance is task-specific and such preferential use during jumping tasks does not always directly translate to sport-specific settings [26]. Limb dominance can emerge as inter-limb muscular strength, balance, jumping, sprint speed, and even change-of-direction-speed imbalances [10, 26]. As such, it has been suggested that athletic qualities of the task are taken into consideration, rather than inferring that the limb-dominance present in one testing procedure will persist to various other sport-specific tasks [26]. Additionally, previous research has demonstrated that inter-limb asymmetry during tasks that require explosive or maximal strength is highly dependent upon the participating muscular groups, whether the motor task is unilateral or bilateral, and whether the strength outcome is focused on power or maximal force output [25]. Our research supports these previous findings and highlights the importance of tracking on-court asymmetries, in addition to more conventional CMJ-based measures of asymmetry testing.

Interestingly, when CMJ asymmetry was compared to different on-court impact acceleration bins (i. e., low, medium, and high), a relationship arose between both PLFA and PPFA and high acceleration on-court impact asymmetry. ► **Fig. 1** and ► **Fig. 2** highlight these relationships, respectively, by visualizing these positive associations. Given that most injuries sustained in basketball occur during rapid change of direction or when landing from a jump [18, 47, 48], these positive associations, particularly during the landing phase of movement and ballistic movements, may enhance the ability for practitioners to “red flag” athletes at a higher risk for injury before they step on court and sustain such injuries in game. Specifically, the concurrent longitudinal monitoring of both CMJ

PLFA and on-court asymmetry during ballistic movements may enable a practitioner to identify trends relative to established and individualized normative baseline values that may be indicative of impending injury or heightened injury susceptibility (i. e., 10–15% is a common threshold for defining when inter-limb asymmetries become a greater cause for concern) [10, 49, 50]. It is important to note that these relationships were negative during medium intensity impacts that would be seen during activities of jogging, running, and some jumping [51]. To clarify, impact accelerations observed on court during normative basketball practices were binned into previously defined low, medium, and high acceleration ranges [32], of which each are representative of different types of movement based upon intensity. Further, overall on-court impact asymmetry displayed a negative association with CMJ PLFA, which may be attributed to the fact that the majority of time spent during basketball practices in the present study existed in a medium impact acceleration range.

Limitations

The present study had several limitations. Firstly, the results are specific to collegiate female basketball athletes and cannot necessarily be generalized to other athletic populations or team sports. Secondly, the on-court basketball scrimmages were used as a surrogate for basketball games; however, there is a likelihood that these were performed at a lower intensity relative to true in-season competitions. Third, given that some basketball athletes jump and land from jumping unilaterally or bilaterally, there is the possibility that on-court asymmetries may be exacerbated as compared to CMJ asymmetries depending on how the athletes take off and land from jumping on court. Thus, it is crucial to identify individual baseline and normative between-limb differences that exist so that meaningful trends are used to guide clinical decision making rather than simply using commonly defined thresholds blindly without contextualizing this data.

Finally, given the task-specific nature of asymmetry and the multifactorial etiology of lower-extremity injuries, it appears there is a need to measure multiple forms of asymmetry. Moreover, obtaining additional subjective metrics on athlete well-being (i. e., pain, sleep quality and quantity, psychological-state, overuse, exertion, etc.) may provide further context and insight into these important and complex relationships. Specifically, future studies may benefit from employing longitudinal study designs, similar to the present study, to assess the variety of measures for athlete asymmetry, along with additional self-report data to create a more holistic, athlete-centered approach to tracking inter-limb asymmetries and injury susceptibility.

Conclusion

Despite the significant associations found, it appears that CMJ testing may measure independent and unique aspects of inter-limb asymmetry as compared to what is seen on court in a sport-specific setting, as evident in the minimal percentage of variance in the data explained. Thus, when analyzing meaningful trends in inter-limb asymmetry for identifying athletes with increased susceptibility to sustain a lower extremity injury, a more holistic model that

encompasses several forms of lower limb asymmetry may be more adept and necessary. Practitioners, sports biomechanists, and strength and conditioning personnel may benefit from adopting the use of wearable inertial measurement units, in conjunction with force-plate testing in longitudinal settings, to track on-court impact asymmetry in basketball athletes that may provide further indication of between-limb differences that adversely affect sport performance and heighten injury susceptibility.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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