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Effect of Ball Inclusion in Drop Vertical Jump Test on Performance and Movement Variability in Basketball Players

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Abstract: The aim of this study was to assess and compare performance and movement variability (MV) in both bilateral and unilateral vertical drop jumps (DVJs) under conditions involving the incorporation or exclusion of ball catching. Twelve amateur basketball players were recruited for participation in the study (seven females and five males). Participants performed three jumps in each of the six conditions analyzed in randomized order: bilateral DVJ without (BNB) and with ball (BB); unilateral DVJ right leg without (RNB) and with ball (RB); and unilateral DVJ left leg without (LNB) and with ball (LB). MV and DVJ performance parameters were analyzed with an accelerometer and a force platform. MV was quantified using the sample entropy (sample entropy; SampEn) derived from the acceleration of the lower back. Differences between the different DVJ conditions were determined with the Wilcoxon test, with a significance level set at $p < 0.05$. The comparisons were also assessed via standardized mean differences (Cohen's d). No significant differences were observed in jump height, contact time and reactive strength index between conditions. However, the RB condition reported higher MV compared to RNB (effect size = 0.79; $p = 0.016$). Similarly, LNB showed greater MV compared to RNB (effect size = −0.62; $p = 0.042$). The inclusion of the ball in the DVJ increased the MV in the bilateral condition and in the right leg, but not in the unilateral condition with the left leg. The asymmetry between legs (right vs. left) in MV values in NOBALL conditions was higher (≈15%) compared to the BALL condition (≈5%).

Keywords: bilateral jump; unilateral jump; dual task; entropy; injury; asymmetry

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1. Introduction

Basketball is a team sport that is characterized by distinctive movement patterns [1,2]. Games are characterized by short and intense periods of activity [3] that require aerobic and anaerobic capacities [3]. The ability to continuously perform high-intensity intermittent actions throughout the game is crucial for performance [2]. Many key actions performed by basketball players involve horizontal movements (sprints and changes of direction), vertical movements (jump shots and rebounds) and combinations of movements within both planes [4,5].

The ability to jump is the basis of many basketball-specific skills, such as shooting, rebounding, dunking, layup, blocking and shot defense [6]. Many of these jumping skills have unilateral requirements, potentially giving rise to the development of asymmetric neuromuscular adaptations in the lower extremities [7]. Considering that basketball-specific skills reliant on vertical jumping are among the most frequently executed actions by basketball players [8], jumping assumes a pivotal role within training programs. Furthermore, jumping is one of the most widely used motor skills for quantifying athletes' physical fitness and monitoring their training [9,10].

To measure the vertical jump in basketball, various tests have traditionally been used, such as countermovement jump (CMJ), drop vertical jump (DVJ), squat jump (SJ) and Abalakov jump (AJ), almost always performed bilaterally [11–13]. These vertical jump assessments are easy to administer and provide a valid assessment of an athlete's physical capacity [14]. However, these jump tests, while valuable, are characterized by a static and predictable nature, presenting a contrast to the dynamic and ever-changing game environment in which players continually adapt their actions [15]. Consequently, both to assess and to improve motor skills in team sports, such as jumping, it is necessary to introduce varied scenarios that encourage dynamic spatio-temporal adjustments in accordance with the specific technical actions and tactical decisions inherent to the game. This approach aims to broaden the motor repertoire involved in jump execution, thereby increasing the athlete's likelihood of success in unpredictable scenarios and concurrently minimizing the risk of injury [16,17].

Furthermore, in basketball, unilateral jump assessments should be included since many technical actions are performed with a predominance of one limb. Recent research on leg dominance and its evaluation posits that a limb subjectively preferred by an athlete may not necessarily exhibit objective dominance in one or more athletic qualities or sport-specific tasks, and that practitioners should select tasks for limb dominance assessment that resemble the most relevant demands of the sport [18]. In the assessment of lower limb asymmetries, the drop jump (DJ) is one of the tests of choice, due to its direct relationship with anterior cruciate ligament injury [19]. Another particularity to consider is the incorporation of cross-laterality, involving jumps with the supporting leg crossed to the hand, a technique employed in passing or shooting scenarios [20].

Conventional injury prevention programs that focus on strength, balance, plyometrics and central control in isolation are moderately effective, but they do not consider the cognitively challenging sport environment [21,22]. These programs may not incorporate task constraints accounting for all factors affecting injury risk, such as reaction time, processing speed and visual and verbal memory, that are present in the game [23]. In recent years, there has been growing interest in understanding the potential impact of cognitive factors (e.g., attention and decision making) on the occurrence of sport-related injuries [24–26]. In this line, Imai et al. [25] reported greater hip and ankle joint moments during the dual task (sum of two digits). Similarly, Zamankhanpourla et al. [24] observed greater knee abduction and less knee flexion during the dual task (digit countdown).

The impact of task constraints on postural destabilization during unilateral jump assessments can be measured through movement variability (MV), which is defined as the variability of the execution of repetitions of an exercise [27]. MV assesses the regularity of movement and is an indicator of motor control [28]. When athletes perform tasks with constraints, the physical and/or cognitive load may increase. Linear measurements have several limitations, especially in determining the degree of movement complexity [29]. A nonlinear approach, such as entropy measures, can address these limitations and better describe changes in postural control [30,31]. Sample entropy (SampEn) is one of the most widely used entropy measures in sport and health sciences [16,17,32–35].

Previous research has shown that adding coordinative or cognitive demands to a DJ protocol can have a significant impact on lower extremity mechanics [36,37]. Despite this, one of the key limitations of the vertical jump task when applied to testing team sport athletes is the lack of sport-specific task constraints. Although some studies have examined MV behavior with the inclusion of sport-specific task constraints in resistance training [17,38], no studies to date have reported information on MV in dual tasks with the inclusion of sport-specific task constraints during the DVJ action. Therefore, the aim of the present study was to assess and compare jumping performance and its MV in both bilateral and unilateral DVJ scenarios with and without the inclusion of ball catching.

2. Materials and Methods

2.1. Participants

Twelve amateur basketball players (seven females and five males; mean ± SD: age 22.3 ± 2.3 years; height 1.73 ± 0.11 m; body mass 67.6 ± 11.3 kg) were recruited from the TecnoCampus-Mataró (Pompeu Fabra University) and basketball clubs in the Maresme geographical area to participate in the study. The inclusion criteria comprised the following: (i) being a basketball player with at least 5 years of competitive experience; (ii) absence of a history of lower-body surgery; (iii) no acute muscular or articular injury or discomfort on the days of assessment; and (iv) regular training (at least 3 days per week) over the preceding 4 months. All participants were right-handed and right-limb-dominant. Prior to participating, eligibility was assessed through a pre-test health history and relevant information questionnaire. Accordingly, comprehensive written information and oral instructions were delivered to each participant before the commencement of testing, and all participants provided written consent to participate. The study protocol was approved by the Ethics Committee for Clinical Research of the Catalan Sports Council (026/CEICGC/2021).

2.2. Study Design

The present study used a single-group within-subject factorial experimental design. Participants were tested for DVJ from a 30 cm platform and landing with and without catching a ball (BALL and NOBALL conditions, respectively). The following landing and jumping conditions were analyzed (Figure 1): two legs both without and with a ball (BNB and BB), right leg without and with a ball (RNB and RB) and left leg without and with a ball (LNB and LB). The protocols for these tests were designed and adapted based on previous research [39–41]. The dominant leg for each participant was defined as the limb they would use to impulse to jump [42,43]. All tests were performed under similar environmental conditions (20–24 °C and 60–75% humidity) at the same time of day (15:00–17:00 h ± 1 h).

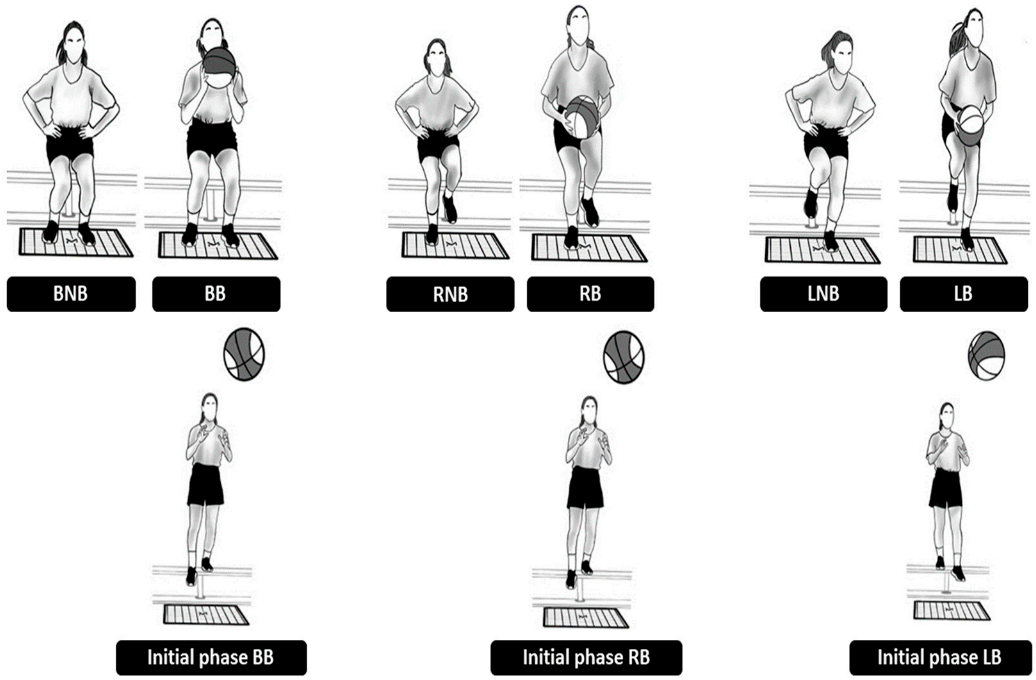

Figure 1. Landing and initial phase of DVJ action; bilateral DVJ without ball (BNB); bilateral DVJ with ball (BB); unilateral DVJ right leg without ball (RNB); unilateral DVJ right leg with ball (RB); unilateral DVJ left leg without ball (LNB); unilateral DVJ left leg with ball (LB).

2.3. Equipment

The acceleration of basketball players was measured using an inertial measurement unit (WIMU, Realtrack Systems, Almeria, Spain; mass: 70 g, dimensions: 81 mm × 45 mm × 16 mm) equipped with a 3D accelerometer recording at 1000 Hz. The WIMU was attached to the lower back of the players, at L4-L5 level, using an adjustable sports lycra belt (Figure 2) [38,44]. This placement close to the center of gravity provides the most accurate representation of whole-body movement [45].

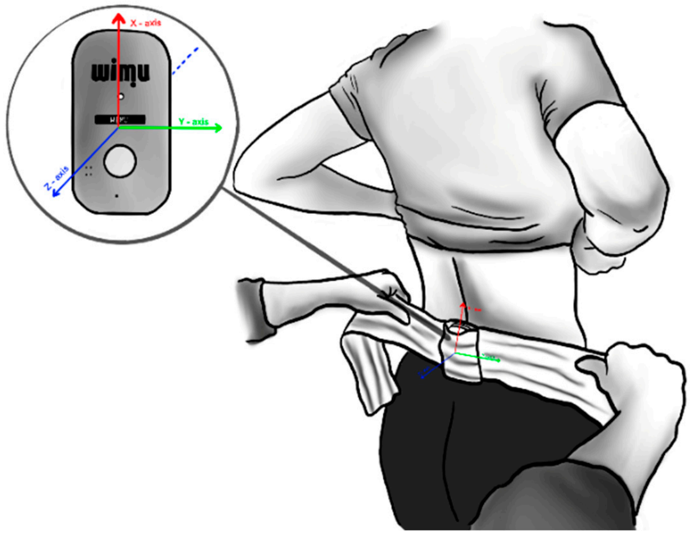

Figure 2. Accelerometer placement at the pelvis (L4–L5).

The force platform (MuscleLab, Ergotest Technology AS, Langesund, Norway; mass: 12.7 kg, dimensions: 60 cm × 40 cm × 7 cm) recorded data at a sampling frequency of 1000 Hz. The force sensors of this platform consisted of four 5 kN strain gauges, with a total maximum force of 20 kN. The force platform was connected to a portable computer using the specific software (MuscleLab V8.27) provided by Ergotest Technology AS.

Performance variables, including jump height, contact time (CT) and reactive strength index (RSI), were obtained from the force platform data (MuscleLab, Ergotest Technology AS, Langesund, Norway). Jump height was calculated using the impulse–momentum theorem [46].

2.4. Data Analysis

For the calculation of MV through SampEn, the raw acceleration signal in the three axes was extracted from the system-specific software (WIMU Software, version 1.0.0, Realtrack Systems SL, Almería, Spain). The total acceleration (AcelT) was calculated by adding the vector components in the three dimensions, vertical (x), mediolateral (y) and anteroposterior (z), following the methodology described by Gomez-Carmona et al. [47] and Moras et al. [17]. SampEn calculation was performed according to Goldberger et al. [48] using dedicated routines programmed in Matlab® (The MathWorks, Natick, MA, USA). The analyses employed a template length (m) of 2 and a tolerance criterion of 0.20. The asymmetry was calculated using the Standard Percentage Difference equation, which has been recommended for accurately calculating asymmetries from unilateral tests: 100/(maximum value from each condition) × (minimum value from each condition) × −1 + 100 [49,50].

2.5. Data Collection

The protocol was performed in two sessions separated by one day. Both sessions started with a standardized warm-up to avoid risk of injury [51]. The warm-up was divided into two parts: the first part consisted of a 5 min activation on a cycle-ergometer at a self-selected speed, followed by 5 min of dynamic stretches involving arms, legs and trunk, akin to a pre-match basketball warm-up. In the first session, prior to the experiment, participants underwent a familiarization session with the test. On that day, they performed two jumps in each of the six conditions analyzed, for a total of twelve jumps. The order of the conditions was as follows: BNB, BB, RNB, RB, LNB and LB (Figure 3). All conditions were previously explained and demonstrated by the researchers. Emphasis was placed on proper technique. Additionally, participants were instructed to keep their hands on their waist during jumps without the ball (NOBALL) to avoid any learning effects. In the second session, participants were instructed to stand on a 30 cm high platform with their hands on their hips, minimizing external interferences. They were then asked to drop vertically and rebound as quickly as possible from initial contact to perform a vertical jump as high as possible [52]. Each participant performed three repetitions of the six different jumps in a randomized sequence (total = 18 jumps), with a recovery time of 60 s between each jump (Figure 3). The mean of the three jumps in each condition was used for further analysis.

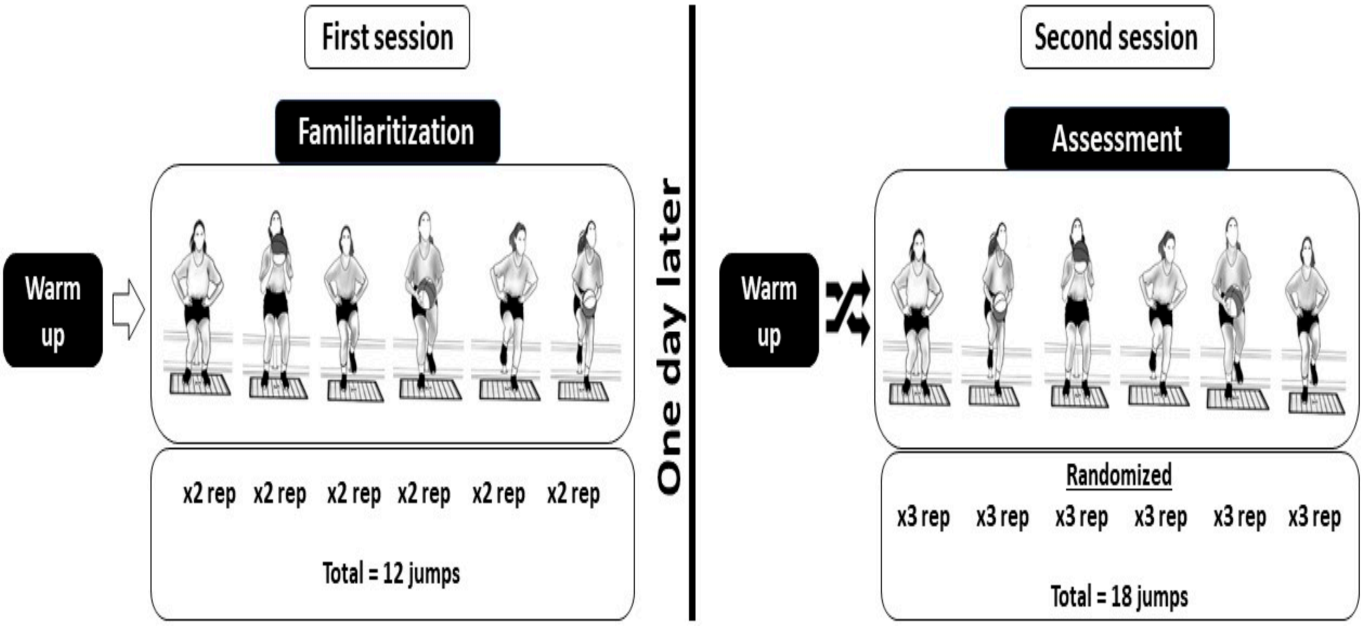

Figure 3. Familiarization and assessment session of DVJ test in the six conditions analyzed.

When performing the BALL conditions, an expert player, who remained the same throughout the entire study, performed a frontal pass from a distance of three meters (Figure 4). Participants were instructed to initiate their movement from the bench the instant the ball left the passer's hands. The evaluated player caught the ball in mid-air, having dropped from the bench to receive it. Throughout data collection, no verbal feedback regarding the quality of the movement or the test outcomes was provided to the participants.

2.6. Statistical Analysis

Statistical analyses were conducted using R (v4.1.2, R Foundation for Statistical Computing, Vienna, Austria). Data representation for each participant and mean values was accomplished using violin plots. The Shapiro–Wilk test was employed to assess normality. Due to the non-normality of all parameters in DVJs, nonparametric tests were used to establish associations between the results. Differences between the different DVJ conditions were determined with the Wilcoxon test, with a significance level set at $p < 0.05$. On the other hand, for the analysis of asymmetries, a t-test for paired samples was applied.

The comparisons were also assessed via standardized mean differences (Cohen's d) and their corresponding 90% confidence intervals. Effect size (ES) thresholds were used to classify the magnitude of the differences: <0.20, trivial; 0.20–0.59, small; 0.6–1.19, moderate; 1.20–1.99, large; and >2.0, very large [53].

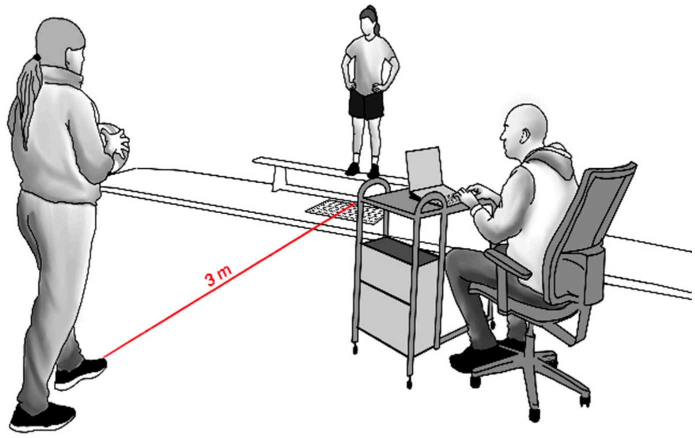

Figure 4. Throwing the ball during DVJ tests.

3. Results

The results obtained in the present study are presented in Figures 5–9. Figure 5 illustrates the DVJ height across the investigated conditions. No significant differences were detected between conditions (BALL vs. NOBALL) or laterality (R vs. L). Additionally, ES were found to be small and trivial (ES < 0.25). Figures 6 and 7 show the RSI and the CT values obtained in the different DVJs, respectively. Similarly, no significant differences were reported between conditions and laterality. Consistent with the DVJ height, ES were small and trivial (ES < 0.25). In contrast to the previous figures, Figure 8 represents the differences in MV (SampEn) in the analyzed DVJs. The RB action reported higher SampEn compared to RNB (p = 0.016; ES = 0.79; Large). LNB showed higher SampEn compared to RNB (p = 0.042; ES = −0.62; Moderate). Additionally, a moderate ES (ES = 0.62) was observed between BB and BNB. Finally, Figure 9 represents the asymmetry between legs in the BALL and NOBALL conditions in the different parameters analyzed. In SampEn, limb asymmetry in NOBALL condition was higher compared to the BALL condition.

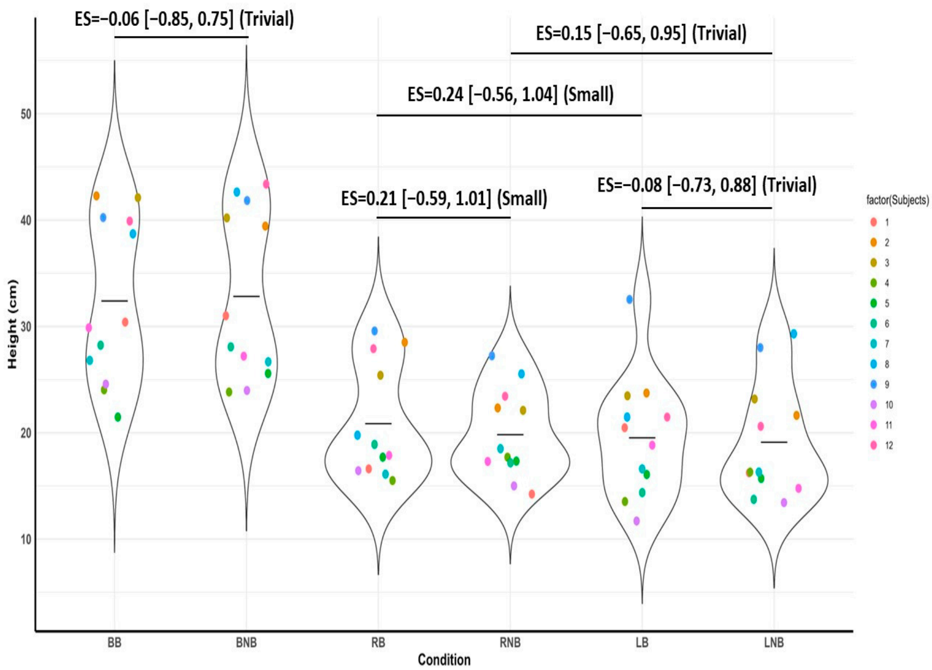

Figure 5. DVJ height in different conditions. BB, bilateral DVJ with ball; BNB, bilateral DVJ without ball; RB, unilateral DVJ right leg with ball; RNB, unilateral DVJ right leg without ball; LB, unilateral DVJ left leg with ball; LNB, unilateral DVJ left leg without ball; DVJ, drop vertical jump; ES, effect size.

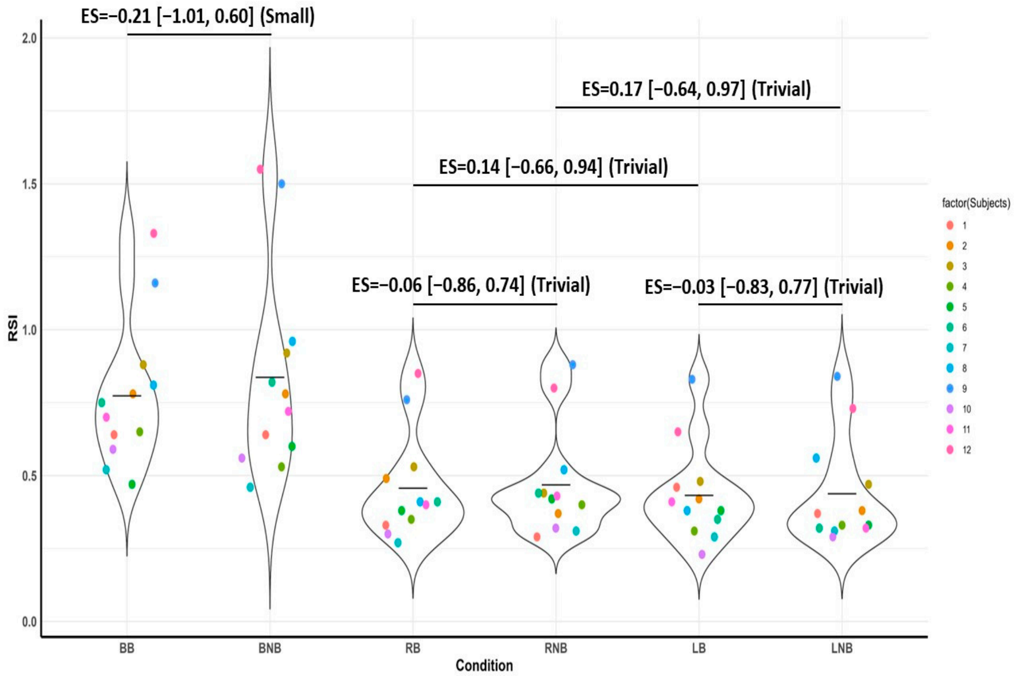

Figure 6. DVJ RSI in different conditions. BB, bilateral DVJ with ball; BNB, bilateral DVJ without ball; RB, unilateral DVJ right leg with ball; RNB, unilateral DVJ right leg without ball; LB, unilateral DVJ left leg with ball; LNB, unilateral DVJ left leg without ball; RSI, reactive strength index; DVJ, drop vertical jump; ES, effect size.

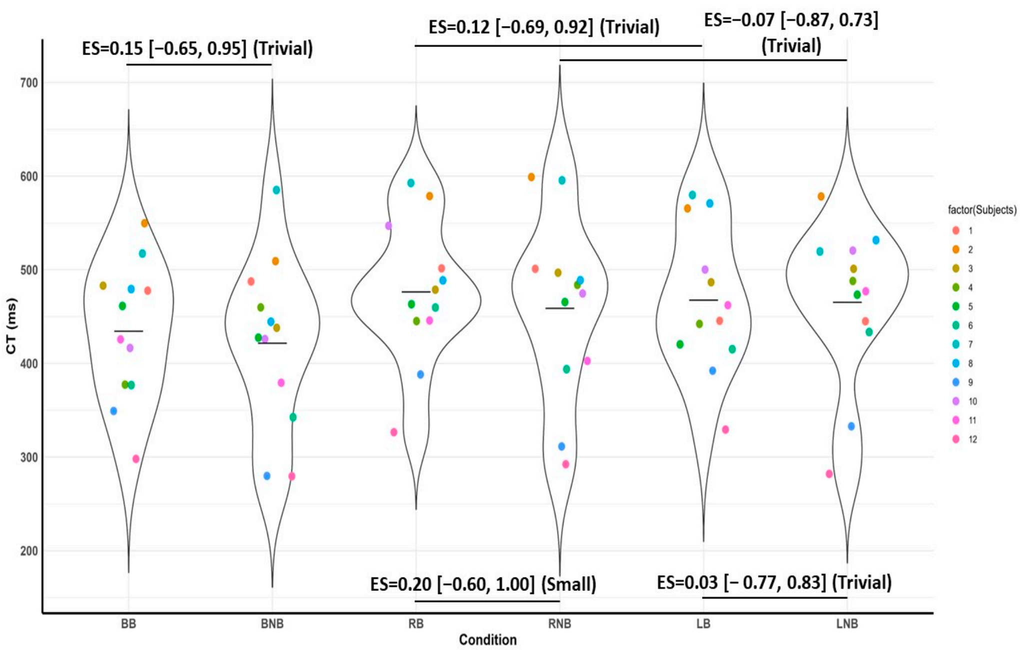

Figure 7. DVJ CT in different conditions. BB, bilateral DVJ with ball; BNB, bilateral DVJ without ball; RB, unilateral DVJ right leg with ball; RNB, unilateral DVJ right leg without ball; LB, unilateral DVJ left leg with ball; LNB, unilateral DVJ left leg without ball; CT, contact time; DVJ, drop vertical jump; ES, effect size.

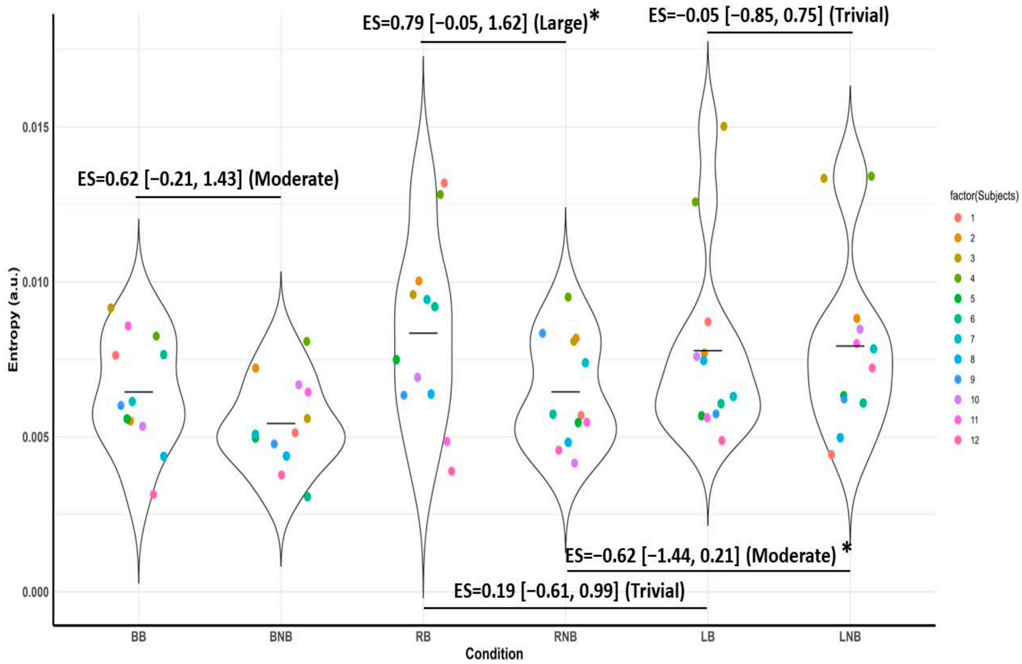

Figure 8. DVJ SampEn in different conditions. BB, bilateral DVJ with ball; BNB, bilateral DVJ without ball; RB, unilateral DVJ right leg with ball; RNB, unilateral DVJ right leg without ball; LB, unilateral DVJ left leg with ball; LNB, unilateral DVJ left leg without ball; ES, effect size. Level of significance at 5% indicated with *.

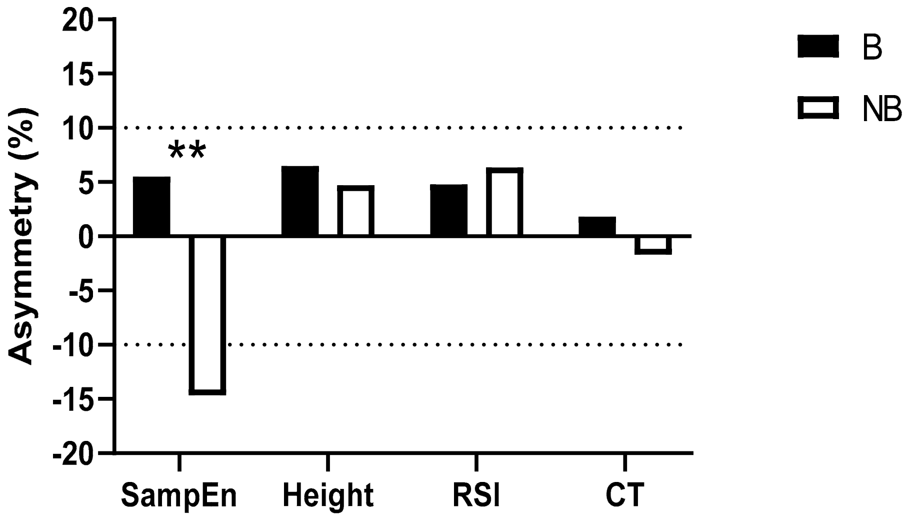

Figure 9. Limb asymmetry of the parameters analyzed under B vs. NB conditions. ** $p < 0.01$ differences B vs. NB; B: Ball; NB: no ball; RSI, reactive strength index; CT, contact time. Negative values are indicative of raw scores being greater on the left limb. Critical thresholds for asymmetry were established at ±10% [54].

4. Discussion

The aim of the present study was to assess and compare jumping performance and MV in both bilateral and unilateral DVJs under conditions involving the incorporation or exclusion of ball catching. The primary findings indicate that, despite the absence of observable differences in traditional DVJ performance parameters (jump height, RSI and CT) when the ball was introduced, MV, as assessed by SampEn, proved sensitive to these variations. Specifically, a substantial increase in SampEn, with a large effect ES, was observed in the right leg when the ball constraint was included in the task (RB vs. RNB). In addition, SampEn values were higher for the LNB condition as compared to RNB with a moderate ES ($p < 0.05$), although trivial ES was noted in RB vs. LB.

MV assesses regularity of movement, which is a recognized indicator of motor control [28]. Hence, MV assumes a crucial role in identifying the amount of perturbation present in a specific sport action [55]. Also, it provides valuable insights about the player's coordination characteristics, in addition to shedding light on the dynamics of the task [56]. While previous studies have analyzed the influence of performing a dual task during DVJs [25,36,52,57] and in sport-specific variations of jumping tests [58,59] on biomechanical and performance parameters, none of these investigations have evaluated MV under different task constraints. Furthermore, to the authors' knowledge, this is the first study to investigate the effect of adding a sport-specific constraint to a classic DVJ test.

In the current investigation, a large and statistically significant increase in MV was noted upon the incorporation of a ball in DVJs executed with the right leg (RB vs. RNB, Figure 8). Likewise, a trend towards a similar effect with a moderate magnitude was observed in bilateral conditions; however, the results did not attain statistical significance (BB vs. BNB, Figure 8). These findings align with those reported in previous research [16,17,38] which demonstrated an increase in entropy when a sport-specific constraint, such as a game ball, was added during an isolated action. The ball catch task involves intercepting a moving object. For successful interception, it is necessary to perceive and anticipate the ball's trajectory by capturing information about its position, the direction and velocity of its displacement, and acceleration or deceleration [60]. The increase in MV observed in the present study could be attributed to a change in the system's coordination patterns or a combination of stability and adaptability of the movement induced by this specific constraint [17].

Regarding laterality, the right leg in the no-ball condition (RNB) was the side that showed lower MV and therefore could relate to greater task dominance. In the same condition, without a ball, the left leg (LNB) showed higher MV values, which can be explained by the natural lower-limb dominance of the subjects in non-specific sport-related tasks (all participants were right-limb-dominant). Interestingly, the addition of the ball constraint to the task produced a large, significant increase in MV in the right leg (RB vs. RNB), but trivial and not significant effects on the left leg (LB vs. LNB). It is important to note that due to the characteristics of basketball, players constantly rely on the opposite leg to their shooting hand in unilateral jumps with the ball [20]. This fact is a plausible explanation of the results shown, as players would theoretically feel more comfortable and be more familiar with a task in which the interaction with the ball is performed on a left-limb stance.

Another important finding is that the addition of the ball during the DVJ action significantly diminished the lower limb asymmetry values calculated through SampEn. Particularly, asymmetry in SampEn values between legs considerably increased ($p < 0.01$) when the ball constraint was included (BALL vs. NOBALL condition, mean asymmetry of 5.5% vs. -14.7%, respectively; see Figure 9). Vertical jump tests represent a viable evaluation method to determine asymmetries [54,61]. Asymmetries between 10 and 15% in different strength indicators of the lower limbs have been associated with reduced jump performance, increased risk of injury and four times higher likelihood of re-rupturing the anterior cruciate ligament [54,62]. In the present study, asymmetries in traditional DVJ performance parameters (jump height, RSI and CT) were below 10%, However, these asymmetries surpassed the 10% threshold when evaluating DVJ without the ball using SampEn (Figure 9). To the best of the authors' knowledge, there is no prior research on asymmetry in MV measured by SampEn in sports movements or tests. Consequently, the interpretation and evaluation of the clinical or practical significance of this finding are constrained. Further research should delve into whether these differences bear meaningful implications for the optimization of the training process.

This study illustrates the potential utility of SampEn entropy as an alternative and more nuanced method for evaluating the effects of sport-specific task constraints despite the absence of significant differences in standardized performance parameters. The use of the ball as a constraint during DVJs demands higher levels of coordination patterns, stimulating the advantageous and adaptive aspects of variability in system function [63]. Traditional injury prevention-oriented tasks are often excessively static and predictable, in contrast to the fact that players must constantly adjust and adapt their actions according to inherent changes in performance environments [15]. Recent research on skill acquisition advocates for the use of constraint-based approaches to improve specificity and develop challenging training environments, which increases MV and adaptability [17,64].

A certain degree of MV in training tasks has been shown to be beneficial, as it challenges the athlete and promotes a system that is more adaptable to internal and external perturbations that constantly act on the organism [16,17]. In the present study, the effect of the ball led to an increase in MV on the right leg, but as previously discussed, not on the left leg. Therefore, in this scenario, it could be interesting to further challenge the constraint when receiving on the left leg, given that players are likely more comfortable in that condition presumably due to transfer from the sport. An option to progress the difficulty could be to combine the sport-specific coordinative constraint (inclusion of the ball) with a cognitive constraint, such as a decision-making component. This approach aligns with the findings of Viñas et al. [38], who demonstrated that adding a decision-making constraint to a ball coordination task resulted in a further increase in MV compared to introducing the ball alone.

This present research is not without limitations: (i) a limited sample size; (ii) the combination of both sexes in the sample; and (iii) the absence of professional players. Future studies should investigate the possible differences between injured and non-injured players, as well as analyze the differences between beginner and expert players. In both cases, motor control and coordination could differ between groups.

5. Conclusions

The introduction of a sport-specific constraint like a ball in the DVJ does not affect performance parameters such us the jump height, RSI or CT. However, it increases MV, especially when using the right leg. The addition of a ball during DVJs reduced asymmetries in entropy values.

This effect was not observed when the motion closely resembled the sport context, and the reception was performed with the left leg. MV analysis could provide more accurate insights about the coordinative demands of the task.

The results of this study highlight the importance of incorporating the analysis of MV in tasks with sport-specific constraints to assess the coordinative demand of real game situations.

6. Practical Application

Coaches can effectively integrate physical and coordinative constraints, tailoring exercises to align with specific on-field tasks and match demands, thereby contributing to the improvement of player performance. The incorporation of a ball into the DVJ exercise enhances coordination and motor control. Introducing diverse scenarios during training promotes dynamic spatial–temporal adjustments aligned with specific technical actions.

Author Contributions: Conceptualization and methodology, S.G.-M., T.C. and B.F.-V.; formal analysis, C.P.-C.B., B.F.-V. and V.I.-D.; investigation, S.G.-M., C.P.-C.B., V.T-R., V.I.-D., L.A.-A. and B.F.-V.; data curation, S.G.-M., T.C. and B.F.-V.; writing—original draft preparation, S.G.-M., T.C. and B.F.-V.; writing—review and editing, V.T.-R., V.I.-D., L.A.-A., T.C., G.M. and C.P.-C.B.; visualization, C.P.-C.B. and B.F.-V.; supervision, T.C., G.M. and B.F.-V. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by Ethics Committee for Clinical Research of the Catalan Sports Council on 9 June 2021 (026/CEICGC/2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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

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