

Drop jump coordination differences in professional and amateur athletes

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Abstract:

Purpose. The drop jump is a symmetrical exercise requiring reactivity and accurate motor control. It involves a rapid sequence of eccentric- and concentric contractions to generate kinetic energy, which is immediately used in the jumping phase. As a result, it is commonly used in both training programs and athlete evaluations. Although its execution has been extensively studied in the literature, further research is needed to confirm the differences in performance between professional athletes (PA) and amateur athletes (AA), particularly in terms of inter-joint coordination and, consequently, left-right symmetry. **Methods.** To this end, we applied elements of kinematic network analysis to evaluate the bilateral synchronization of movement in the shoulders, elbows, hips, knees, and ankles, comparing PA and AA. Borrowing from previous studies that used network theory to assess kinematic relationships between body parts during movement, we analyzed the coordination between left and right joints during the drop jump movement of each participant. **Results.** Using the permutation test we compared the PA group to the AA groups, to verify whether there were differences in coordination, and which joints were involved if it was the case. We found two out of five joints showed significant differences in left-right coordination. The results showed that PA exhibited greater coordination at the shoulders and hips, suggesting a higher level of control to better exploit the upward thrust of the legs and prevent injuries. **Conclusions.** This study demonstrates that professional athletes display superior left-right coordination in the shoulders and hips during the drop jump, suggesting that enhanced joint coordination in these regions may contribute to higher athletic performance.

Key Words: exercise; sport performance; morpho-functional assessment; kinematic network analysis; left-right coordination.

Introduction

The drop jump is a plyometric movement used in athletic and sport training to assess and enhance explosive power, coordination, and neuromuscular efficiency (Ahmadabadi et al., 2023; Pedley et al., 2017). Its execution is composed of different phases that require adequate coordination and rapid tuning of movement control. The movement starts with a drop from an elevated surface, followed by an eccentric phase as the body lands. Then, it rapidly starts a concentric phase to perform a vertical jump (Furuhashi et al. 2022; Moir et al., 2018;). This stretch-shortening cycle is used to enhance reactive strength in muscles and tendons, and finds application in many sports where explosive movements are needed (Markovic et al., 2010; Bobbert et al., 1990). More in detail, biomechanical role of this cycle aims to accumulated energy and exploit it to perform the counter-gravity part of the exercise. Indeed, the eccentric phase, where the muscles stop the fall, counteract the force of gravity, and store elastic energy. This phase is followed by a concentric one, in which the accumulated energy is released to generate an upward vertical thrust (Sole et al., 2022).

Coordination and symmetry between the body's left and right sides are important characteristics of drop jump. For instance, symmetry in bilateral joints' excursion ensures that forces are evenly distributed on both sides of the body, reducing the risk of injury and improving the performance (Crotty et al., 2022; Hamsyah et al., 2024; Wang et al., 2022). Studies have demonstrated that athletes with greater symmetry in joint coordination perform better in explosive tasks, as they are less likely to develop compensatory movement patterns, that makes the execution less efficient and can lead to injury (Ciccodicola et al., 2021; Kotsifaki et al., 2023). Despite the importance of symmetry-related aspects, many studies focus solely on the lower limbs, even though the crucial role of the upper limbs is well known (Laffaye et al., 2006; Raiola et al., 2014). Additionally, comparisons between professional and amateur athletes are scarce, limiting the identification of any asymmetries that may characterize the differences between the two groups.

Some studies showed that athletes with higher levels of neuromuscular coordination perform better in drop jump tests than non-athletes. For instance, Bobbert et al. analyzed the stretch-shortening cycle during drop jumps and observed that elite athletes exhibited higher muscle coordination, leading to greater force output and a more effective jump (Bobbert et al., 1996; Montoro-Bombú et al., 2024; Yoshida et al., 2024). Furthermore, McMahon and Cheng analyzed the joint kinematics of the lower limbs during drop jumps reporting that high level athletes demonstrated a more synchronized movement pattern between the hip, knee, and ankle joints (McMahon, & Cheng, 1990). The authors reported that this optimized coordination may help improve jump height while reducing landing forces, which, in turn, may protect against injuries. In accordance to McMahon and Cheng findings, Hart et al. reported that interlimb asymmetry is more common in amateur or recreational athletes compared to professional athletes, with the former showing significant differences in force production between their left and right limbs (Hart et al., 2016). Furthermore, this asymmetry has been associated with a higher incidence of lower limb injuries, particularly in sports that require repetitive jumps, and changes in direction (Silva et al., 2022;).

While numerous studies have investigated inter-limb symmetry, most have focused solely on linear measurements or individual biomechanical parameters, neglecting a more comprehensive and integrated analysis of limb coordination. Our research introduces an innovative approach that not only builds upon established coordination methods but also applies them in a broader and more in-depth context to achieve a deeper understanding of limb dynamics. Specifically, this study addresses the following gaps: i) Lack of dynamic coordination analysis: Current literature rarely considers changes in coordination during complex movements. Our work offers a dynamic perspective that accounts for temporal and spatial variations; ii) Limited application of coordination analysis methods: While these methods have been developed in other fields, their potential in assessing inter-limb symmetry remains largely unexplored. This study adapts and extends these approaches to yield more meaningful insights; iii) Insufficient integration of theory and practical application: We bridge the gap between theoretical models and practical implications, making the results more relevant to the scientific community and practical applications in clinical or sports settings. In summary, this study not only deepens the understanding of inter-limb symmetry but does so through a methodology that integrates and surpasses the limitations of previous research, opening new avenues in the field of movement analysis.

In this study, we aim to analyze inter-limb symmetry by adopting coordination analysis methods from previous approaches. Specifically, recent studies has evaluated coordination through a network-based approach that, drawing on network theory, is able to characterize the relationship occurring among different elements belonging to the same system (Barabasi, 2016). This method is widely applied in different fields, such as sociology, climatology, and neuroscience (Sorrentino et al., 2022; Troisi Lopez et al., 2023). Applied to kinematics, this approach views the body as a network and the kinematic relationships between body parts as coordination (Minino et al., 2024; Romano et al., 2024; Troisi Lopez et al., 2022a-b). This coordination is estimated using the Pearson correlation coefficient between pairs of time series describing the kinematics of the point of interest. This approach proven itself useful in characterizing subject-specific pattern (Cipriano et al., 2023; Romano et al., 2022) of movement, and in representing the main characteristics of the performed movement. Using this approach, we aim to compare the inter-limb coordination of five body joints (i.e., shoulders, elbows, hips, knees, and ankles) in professional athletes (PA) and amateurs (AA) during the drop jump, with the goal of identifying potential differences and their localization. Hence, using an online available published dataset, we analyzed data from PA and AA during drop jump. We expect that professional athletes will exhibit greater coordination in both the upper and lower limbs. Specifically, we hypothesize significant differences in the shoulders and knees, as they provide some of the main contributions to the observed movement.

Material & methods

In this study, we used a dataset published by Zhao et al. (2023), which includes kinematic time series recorded via a stereophotogrammetric system. This dataset captures 30 different movements performed by 183 athletes, involving both mobility and stability tasks such as back bends, shoulder abductions, and drop jumps. More details about the acquisition system, sample population, and specific movements are available in the original paper²¹. For our analysis, we concentrated on the time series of joint excursion angles for twelve joints: the neck, trunk, and bilateral shoulders, elbows, hips, knees, and ankles. Three-dimensional time series (anteroposterior, mediolateral, and vertical) were available for each joint.

The data underwent an individual inspection to identify label mismatches, missing values, anomalies, and ensure consistency (e.g., maintaining a consistent data order). Missing values were interpolated using MATLAB's 'fillmissing' function with the 'spline' method if the gap was under 0.1 seconds; otherwise, the participant's data were excluded. Furthermore, only included participant that practiced high mobility sports (i.e., football, basketball, soccer), and whose age was higher than 18. Following this screening, the final sample included 42 participants, that were divided into two groups, i.e., professional athletes (PA, $n = 21$), and amateur athletes (AA, $n = 21$).

Borrowing from previous studies that used network theory to assess kinematic relationships between body parts during movement, we analyzed the coordination between left and right joints during the drop jump movement of each participant. In particular, we measured the coordination on the sagittal plane of the acceleration of shoulders, elbows, hips, knees, and ankles, using Pearson correlation coefficient as proxy for coordination, as it corresponds to the standardized covariance of joints' acceleration. Then, the values were compared between the PA and the AA groups, using a permutation test. Such a test compares the actual absolute difference of the joint values to a surrogate distribution, composed of 10'000 absolute differences calculated using two surrogate groups constituted by randomly assigned participants at each iteration. Then, p-values were corrected using false discovery rate (pFDR), and only pFDR < 0.05 were considered as significant.

Results

Using the permutation test we compared the PA group to the AA groups, to verify whether there were differences in coordination, and which joints were involved if it was the case. We found two out of five joints showed significant differences in left-right coordination. Specifically, shoulders and hips of PAs (shoulders = 0.79 ± 0.14 ; hips mean = 0.40 ± 0.23) displayed significantly higher values (shoulders pFDR = 0.03; hips pFDR = 0.009) than AAs (shoulders = 0.66 ± 0.19 ; hips = 0.2 ± 0.15). On the contrary, elbows (pFDR = 0.89), knees (pFDR = 0.26), and ankles (pFDR = 0.26) did not present significant differences.

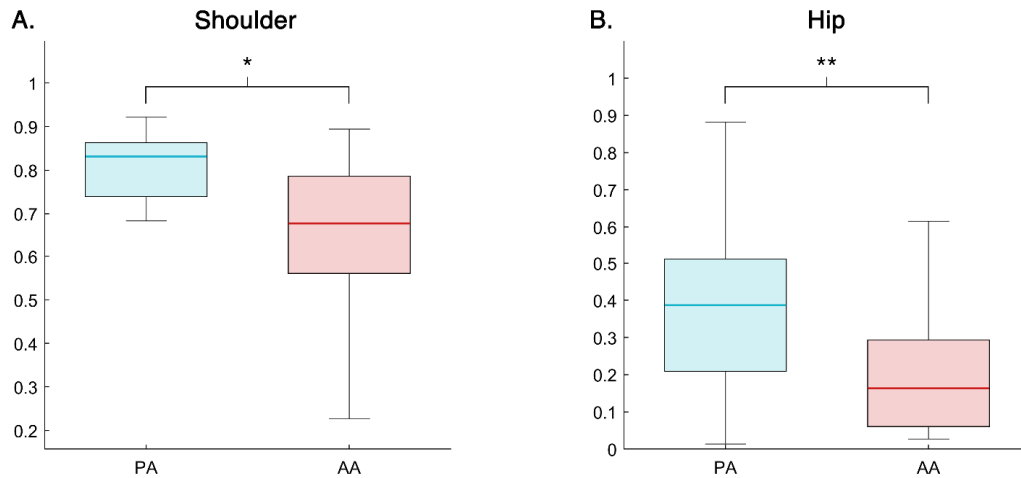


Figure 1. Coordination comparison. The figure shows the boxplot representing the inter-joint coordination values during drop jump. PA = Professional athletes; AA = Amateur athletes. * $p < 0.05$; ** $p < 0.01$.

Discussion

Based on previous studies that utilized network theory to estimate human movement coordination, we measured the interlimb coordination of shoulders, elbows, hips, knees, and ankles during the drop jump. This movement displays a high level of symmetry. We compared the results between professional and amateur athletes, finding a significant difference in the coordination of shoulders and hips, with professional athletes showing greater coordination.

These results suggest that following professional-level training, athletes develop neuromuscular control that enhances coordination and movement precision during the drop jump task. As for inter-shoulder coordination, it highlights the importance of the upper body in contributing to this type of exercise. In fact, while the lower limbs primarily generate the force required for the jump, the arms help optimize balance maintenance and contribute to the momentum during the ascent (Benamini et al., 1995; Zhao et al., 2023). In this regard, a study by Bobbert et al. (1996), showed how arm swing significantly contributes to vertical jump performance by raising the center of mass and stabilizing the trunk during takeoff. Indeed, the relevance of the relationship between trunk position and center of mass control is reported in many studies (Duchateau, & Amiridis, 2023; Jo, 2008; Sortwell et al., 2021; Troisi Lopez et al., 2021;), as well as the contribution of arm swings to jumping movement. For instance, Lees et al. showed that in volleyball athletes, arm swing produced an increase in jump height ranging from 12 to 15%. Additionally, in the same study, the authors demonstrated that the contribution of the arms also increased the peak ground reaction force, highlighting the biomechanical advantage of using the upper body (Lees et al., 2004). Regarding the hips, their involvement in shock absorption during the jump and in reducing injury risk has been repeatedly observed. Optimal hip synchronization would help maintain proper posture and avoid twisting that could lead to load imbalances (Hara et al., 2006; Wang & Liu, 2024). Indeed, the hip contributes to generation, absorption, and transfer of forces during takeoff, flight, and landing phases. The hip muscles, particularly the hip extensors, are essential for force production during takeoff, facilitating hip extension, and

contributing to the upward movement. Bobbert et al. (1996), showed that efficient hip extension correlates with higher jump performance, and, in general, athletes who exhibit better coordination in hip-knee-ankle extension are able to optimize their force production during jumps (Monfort-Torres et al., 2024; Meylan et al., 2010). Furthermore, Nguyen et al. (2018), reported that, during the landing phase, the hip control contributes to injury prevention, by managing the forces that act on the knee and ankle joints. The authors, analyzing data concerning female soccer players who used a hip-dominant landing strategy, reported that the athletes were able to reduce knee abduction moments, which are linked to ligament injuries. This finding highlights the importance of the hip in stabilizing the lower limbs and controlling landing mechanics. When the hip movements are not adequately tuned or fatigue is present, as reported by Carcia et al. (2005), the ability to absorb impact is lowered, determining a shifting of the load towards the knees, hence increasing the risk of injury.

It is important to note that no significant differences were found in the interlimb coordination of elbows, knees, and ankles. Although elbows are not widely studied, Baus et al. suggest that their flexion may positively contribute to improving jump performance (Baus et al., 2022; Bechet et al., 2024; Pechlivanos et al., 2024). Regarding the knees and ankles, several studies agree on their importance in the execution of the drop jump. Ankle dorsiflexion also impacts both knee and ankle mechanics during drop jumps, with limitations in range of motion leading to altered joint angles and increased strain on the lower limbs (Earl et al., 2007; Feng et al., 2024; Radu et al., 2024). Further studies also show that repetitive jumps from different heights can increase asymmetry between the knees and ankles, affecting performance and injury risk, particularly at higher heights (Gu et al., 2025; Zhang et al., 2021). Additionally, individuals recovering from injuries such as ankle sprains display altered bilateral coordination, with higher asymmetry and reduced ankle flexion during drop jumps (Doherty et al., 2015). The lack of such differences in these joints could be due to various factors. Our sample may not be large enough to capture these differences. From another perspective, the joints that did not show significant differences might be easier to manage, even for amateur athletes, and thus the results do not present notable variations. In any case, further studies are needed to confirm our findings and to validate additional hypotheses regarding the lack or presence of other significant differences. Furthermore, future studies may also focus on investigating the presence of correlations between performance and cognitive aspects in both PA and AA groups (McCarthy et al., 2011; Passarello et al., 2022).

Conclusions

In conclusion, this study demonstrates that professional athletes exhibit superior left-right coordination in the shoulders and hips during the drop jump, suggesting that enhanced joint coordination in these regions may play a critical role in achieving higher athletic performance. This finding underscores the importance of joint coordination as a fundamental aspect of athletic ability, particularly in explosive and high-impact movements like the drop jump. The practical implications of these results are significant. For coaches and trainers, understanding the role of joint coordination offers an opportunity to design targeted training programs that focus on optimizing shoulder and hip coordination. This could involve incorporating exercises aimed at improving neuromuscular control, symmetry, and dynamic stability in these joints. Such training interventions may not only enhance performance but also reduce the risk of injuries, particularly those related to imbalances or poor movement mechanics. Moreover, this study highlights a potential pathway for bridging the performance gap between professional and amateur athletes. Amateur athletes often display greater asymmetries and less efficient movement patterns, which may limit their performance potential and increase their injury susceptibility. By identifying and addressing these deficits through specific coordination-focused training, amateur athletes could improve their performance and reduce injury risks.

Further research is needed to explore the underlying mechanisms of these coordination differences, including the role of proprioception, muscle activation patterns, and central nervous system adaptations. Additionally, longitudinal studies should investigate whether systematically improving coordination in the shoulders and hips leads to measurable gains in performance metrics such as jump height, sprint speed, or agility, as well as a reduction in injury incidence. The findings of this study emphasize the broader relevance of joint coordination beyond elite sports. By applying the insights gained here, practitioners in rehabilitation settings could develop strategies to restore or enhance joint coordination in injured individuals, potentially accelerating recovery and improving outcomes. Ultimately, this research provides a foundation for understanding how refined motor control and joint coordination contribute to athletic success and opens new avenues for developing evidence-based interventions that benefit both professional and amateur athletes alike.

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