HAH913E Physical Activity Accelerometry Project : Instrumented analysis of three jump types using an Axivity AX3 accelerometer and Kinovea

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Contents

1 Introduction

Human movement relies on the integration of multiple mechanical and neuromuscular parameters, such as force, speed, intersegmental coordination, and power output, the analysis of which allows for a better understanding of the determinants of motor performance. The vertical jump is a particularly relevant model for studying these mechanisms, due to its explosive nature and its functional importance in many sports. Although jumping performance is classically associated with the force-producing capacity of the lower limbs, it is now accepted that the upper limbs also play a crucial role in the success of the movement.

Several studies have shown that arm swing significantly increases jump height by contributing to the elevation of the center of mass and an increase in takeoff speed [2] [4]. This phenomenon can be explained in particular by a segmental inertia effect, improved transfer of mechanical energy through the kinetic chain, and an increase in the force generated by the lower limbs [2]. In trained athletes, this contribution is enhanced by better inter-segmental coordination, allowing for more efficient synchronization between arm and leg actions. The addition of a run-up further accentuates these effects by increasing overall impulse and jump height [1]. Recently, Kacem et al. [3] also demonstrated a performance gain of over 20% during jumps performed with arm swing compared to jumps without active upper limb involvement. In this context, arm speed and acceleration appear as key performance parameters, likely to reflect the mechanical efficiency of the movement. Thus, measuring wrist acceleration using inertial sensors allows for an objective quantification of the arm's contribution to the vertical jump.

The goal of this project is therefore to analyze the impact of arm movement on jump performance by relating acceleration measured by accelerometry to jump height assessed by video analysis, in order to better understand the biomechanical mechanisms underlying the production of the vertical impulse.

2 Methods

2.1 Participant

The participant is an experienced competitive basketball player, with regular and structured training that ensures the automatization of the technical skill. The selection of such a profile was intended to minimize the intra-individual variability often associated with motor learning and to analyze a stable biomechanical model. This approach allows for a case study focused on a technically mastered movement.

2.2 Tools

Arm acceleration is recorded using an Axivity AX3 sensor, attached to the wrist. The Axivity AX3 is a small, triaxial accelerometer designed for measuring physical activity. It records raw acceleration on three orthogonal axes, with a configurable sampling rate from 12.5 Hz to 3200 Hz, a configurable measurement range from ±2 g to ±16 g, 512 MB of internal memory for extended recording, and a lightweight, waterproof casing for comfortable wrist wear.

Figure 1: Axivity AX3 sensor

In this study, the sensor is worn on the wrist to primarily capture acceleration related to arm movement during the different jumping modalities. Raw data is exported in text or CSV format from the associated Axivity software and then processed offline. Jump height is assessed from a video recording, analyzed using Kinovea software. Kinovea is a free and open-source two-dimensional motion analysis software specifically designed for video analysis in sports contexts. A video camera (4k/60FPS) is positioned in profile, at a sufficient distance to capture the entire body during the jump. The camera frame rate is chosen to allow for precise identification of the takeoff, jump, and landing phases.

2.3 Experimental Protocol

The goal is to study the impact of arm movement and the approach run on the vertical jump. Participants perform three types of vertical jumps after a standardized warm-up. The first type is a vertical jump without arm movement.

The participant jumps from a standing position with arms at his sides, remaining fixed throughout the takeoff, flight, and landing phases. This first type of jump serves as a baseline measurement, allowing for the evaluation of jump performance in the absence of active upper limb contribution. The second type of jump is a vertical jump with arm movement. The participant also starts from a standing position with arms at his sides, but this time performs a full, natural, and maximal arm swing backward and then forward during the takeoff phase before performing the vertical jump. This allows for the study of the specific effect of arm movement on jump height and movement dynamics. The third type of jump includes an approach run. Starting with a short approach phase, the participant performs a dynamic takeoff with active arm swing, followed by a maximal vertical jump. This condition aims to replicate a situation closer to a real-world sporting context and to analyze the combined effect of horizontal momentum and segmental arm coordination on vertical jump performance.

A recovery period of 5 to 10 seconds is allowed between each jump. The participant is instructed to perform each jump at maximum intensity, replicating the same technique as closely as possible from one attempt to the next. These attempts are recorded simultaneously with the Axivity AX3 wrist accelerometer and with the camera used for analysis via Kinovea.

2.4 Kinovea Analysis

A comparative biomechanical analysis was performed using the Kinovea video processing software to quantify the influence of the arm swing on vertical jump performance. The protocol began by setting up a dual-screen display allowing for the simultaneous visualization of the jump without arm swing and the jump with arm swing.

The first processing step involved temporally synchronizing both sequences. The synchronization point was set at the precise takeoff frame, defined as the last moment of foot contact with the ground, in order to observe the temporal difference during the flight phase and upon landing. Spatial calibration was then performed on each video using the subject's height as a metric reference, thereby allowing the software to convert pixels into centimeters.

Performance measurement was carried out using two complementary methods. A temporal method was first employed using the stopwatch tool to measure the flight phase duration between takeoff and landing, which allowed for the calculation of the theoretical jump height. A direct spatial method was subsequently applied by freezing the video at the jump apex to measure the vertical distance between the ground and the subject's heels using the line tool.

Finally, the analysis focused on the horizontal components of the movement. The use of visual markers and distance measurement tools allowed for the quantification of the subject's forward horizontal displacement, highlighting the modification of the center of mass trajectory induced by the momentum transfer from the upper limbs.

2.5 Acceleration data acquisition

The Axivity AX3 sensor is configured to continuously record triaxial acceleration throughout the jump session. The raw signals are exported as a CSV file containing one column for time and three columns corresponding to the acceleration components on the X, Y, and Z axes. Because the sensor is worn on the wrist, the acceleration variations primarily reflect segmental movements of the forearm and upper arm during the jump takeoff.

2.6 Signal processing

Signal processing is performed using Python scripts available on GitHub under "Code 2". The CSV files generated by the AX3 are imported using the pandas library, and the columns are then renamed consistently to clearly identify time and the three acceleration axes. The time column is converted to a date/time format, and the acceleration components are transformed into numerical values and then scaled to be expressed in g-units.

Acceleration time series along the X, Y, and Z axes are then plotted for each session to verify data quality and visually identify the periods corresponding to jumps. From these visualizations, time intervals are manually defined to isolate the motion sequences corresponding to the jumps. These intervals are then used to extract the relevant signal portions for analysis.

To characterize the overall intensity of wrist movement, the magnitude of the acceleration vector is calculated from the three components X, Y, and Z, yielding a scalar signal reflecting the resulting acceleration during the takeoff phase of the jump. In a reference dataset, three time windows corresponding to the three types of experimental jumps are precisely extracted: a jump without arm movement, a jump with arm movement, and a jump with arm movement combined with a running start. For each of these windows, the script selects the most relevant acceleration component, in this case the X component, primarily associated with the arm swing. The orientation of this axis is corrected if necessary to ensure consistency in the direction of acceleration between trials, and then the maximum acceleration value is calculated over the interval corresponding to each jump.

This yields, for each type of jump, a maximum value representative of the arm acceleration at the moment of takeoff. The scripts then calculate various ratios between these maximum values, corresponding to relative comparisons between jump types, including between the arm jump and the no-arm jump, between the arm jump and the arm jump with a running start, and between the arm jump plus a running start and the no-arm jump. These ratios quantify the relative increase in arm acceleration induced by arm movement alone and by the addition of a running start and provide indicators of the impact of segmental coordination on movement dynamics.

3 Results

3.1 Accelerometer

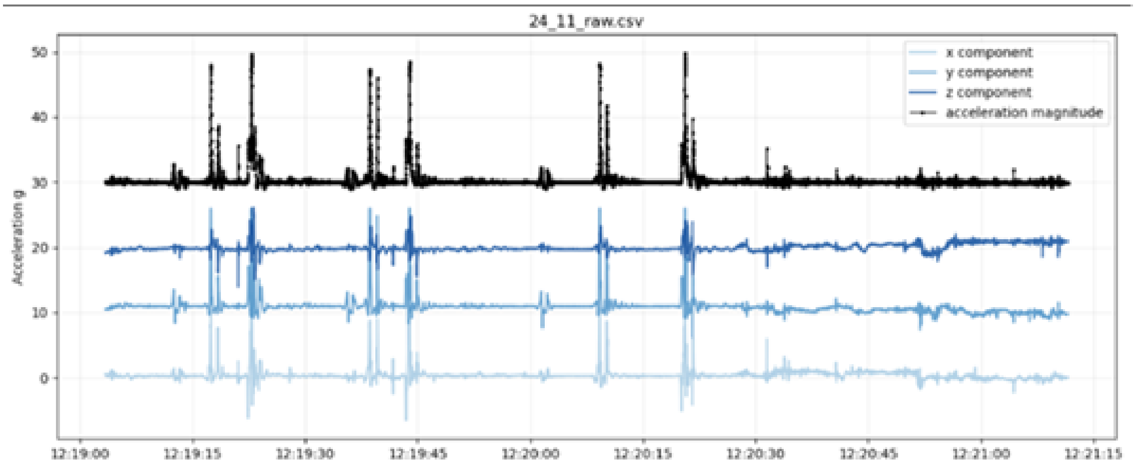

Figure 2: Acceleration along the sensor's X,Y,Z axis and total acceleration magnitude

This graph shows the tri-axial acceleration recorded during three sequences of jumps in the order of: no arms movement, with arm movement and with arm movement and run-up. The sequences start at 12:19:10, 12:19:35 and 12:20:00 respectively. Due to the placement of the accelerometer wristlet, the acceleration along the body's vertical axis is recorded along the accelerometer's X and Y-axis. The acceleration recorded along the accelerometer's Z-axis corresponds to transverse movements and is thus lower than along the X-axis and Y-axis. Furthermore, 1 g was substracted to the total acceleration magnitude to account for the effects of gravity. Peak acceleration across the three jumps types is the highest along the Y-axis and the lowest along the Z-axis, which matches with the movement and the sensor's orientation. Across the three axis, the acceleration is the highest for the jump with arms movement and run-up and lowest for the jump without arms movement.

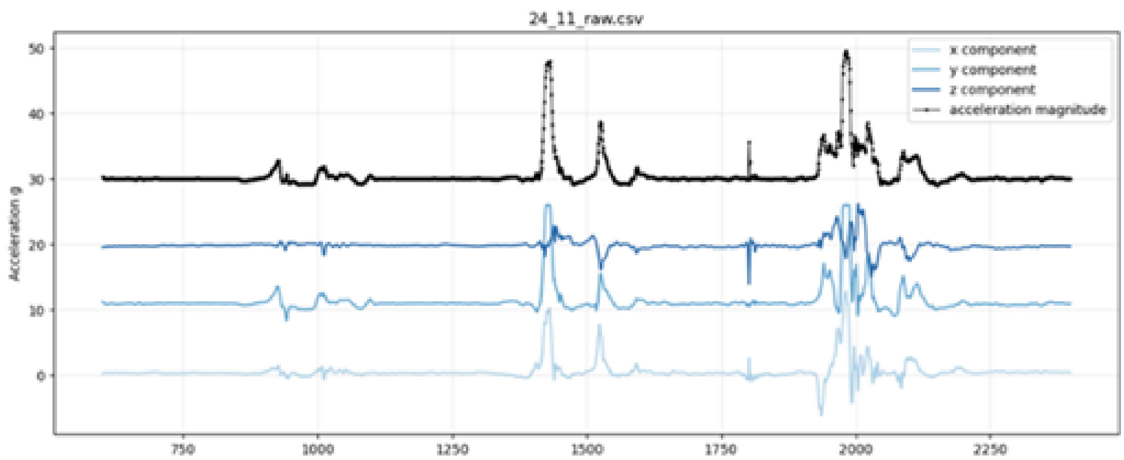

Figure 3: Acceleration along the sensor's X,Y,Z axis and total acceleration magnitude

This graph shows the tri-axial and total acceleration during one jump sequence (beginning at 12:20:00 on the previous graph). The acceleration along the Y-axis exceeds the sensor's maximum range of 16 g during the two jumps with arms movement, but the acceleration along the X-axis does not and has been transcribed into the following table.

Jump	**X-acceleration (g)**	**Acceleration without arms movement ratio**
Without arms movement	1.47	1
With arms movement	10.25	6.98
With arms movement and run-up	12.88	8.77

Table 1: Peak acceleration along the X-axis and ratio with the acceleration during a jump without arm movement for each jump type

The peak acceleration along the X-axis is thus about seven times higher during a jump with arms movement than without arms movement. The acceleration is further increased during the jump with arms movement and run-up. This highlights the role of both arms' movement and the run-up on inertia during the jump.

The code calculates the magnitude of the Euclidean and subtracts to isolate the acceleration related to movement, utilizing the fact that the sensor's X and Y axes (worn on the wrist) primarily measure the vertical component (see the section "Sensor placement and axis study" in the notebook). The analysis (referencing cell 39 of the notebook) reveals that the maximum acceleration peak is significantly higher when the arms are used (the ratio of the peaks is calculated to be approximately 6.98 compared to the jump without arms). According to the fundamental principle of dynamics F=m x a, an increase in the acceleration (a) recorded during the push-off, for a constant mass (m), signifies that the jumper exerted a greater net force (F) against the ground.

3.2 Kinovea Analysis

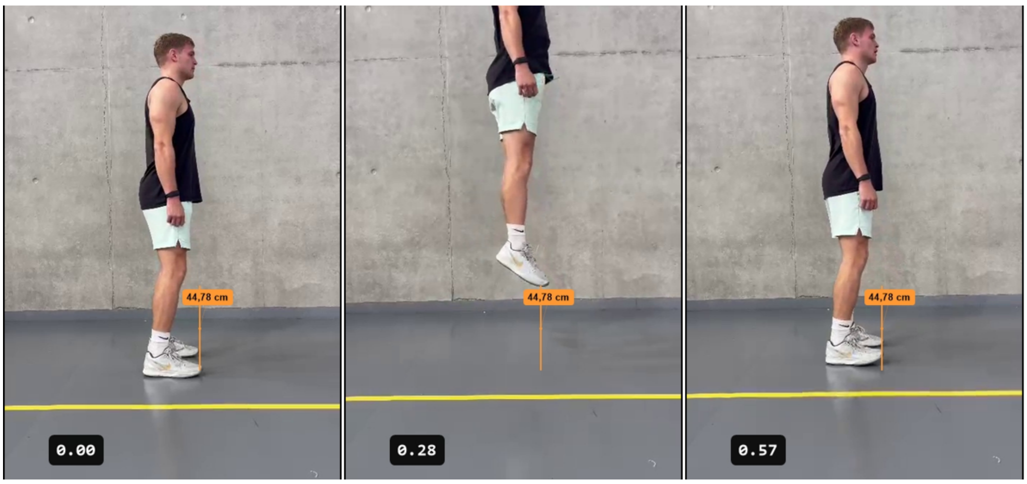

Figure 4: Acceleration along the sensor's X,Y,Z axis and total acceleration magnitude

The analysis of the video using Kinovea and the processing of raw accelerometer data via the Python script constitute a complementary study of jump performance, where dynamics (forces) explain kinematics (movement).

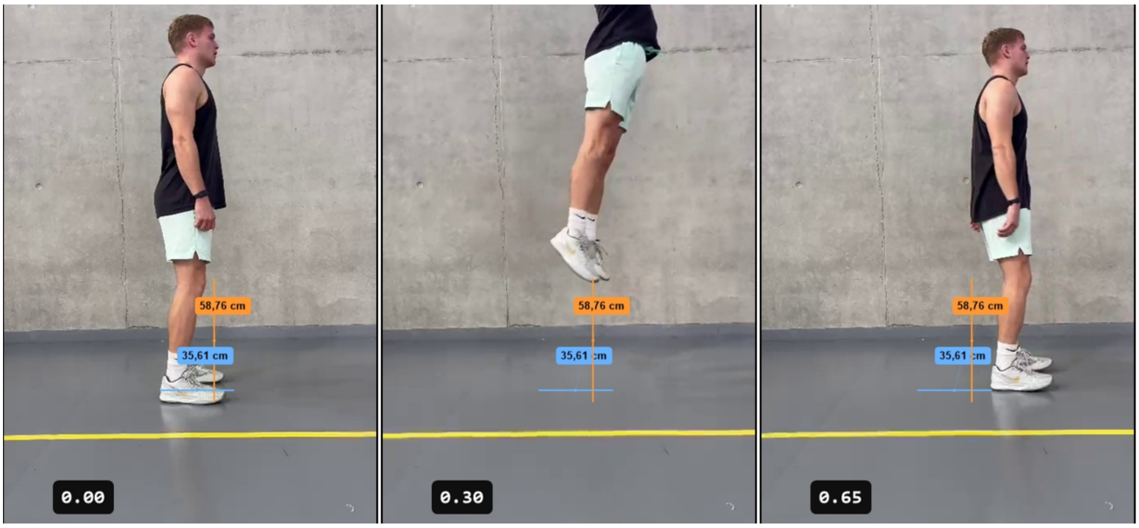

Figure 5: Acceleration along the sensor's X,Y,Z axis and total acceleration magnitude

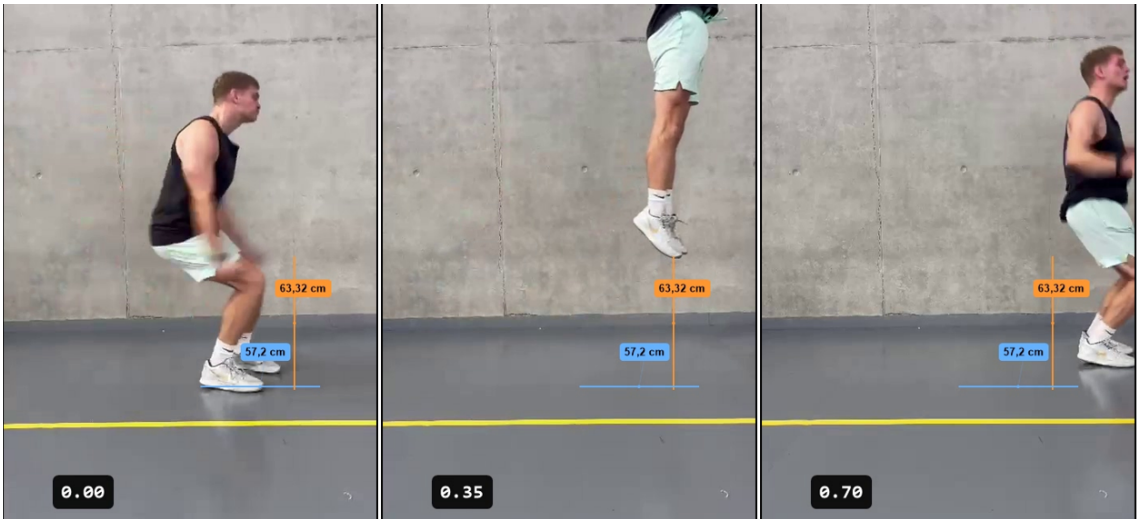

Figure 6: Acceleration along the sensor's X,Y,Z axis and total acceleration magnitude

For the baseline jump without arms, a flight time of 0.57 seconds was recorded. Applying the gravitational equation of motion $h = 1/8 * g * t^2$, this duration yields a theoretical height of 39.8 cm. Similarly, the jump with arm swing recorded a flight time of 0.65 seconds, corresponding to a theoretical height of 51.8 cm. Finally, the jump with run-up recorded a flight time of 0.72 seconds, corresponding to a theoretical height of 63.5 cm. Although minor discrepancies exist due to the precise identification of takeoff frames, the convergence of results between these spatial and temporal methods validates the accuracy of the video analysis.

The video analysis demonstrates a clear hierarchical progression in performance based on the spatial measurements. The baseline countermovement jump without arm swing resulted in a height of 44.78 centimeters. The introduction of an active arm swing from a static start significantly increased this height to 58.76 centimeters. Finally, the inclusion of a run-up optimized the movement further, reaching a peak height of 63.32 centimeters. This progression highlights that the mechanical energy contribution from the upper limbs and approach velocity accounts for a substantial portion of the total vertical displacement.

Cross-referencing these kinematic results with kinetic data from the accelerometer provides a mechanical explanation for the observed performance gains. The accelerometer recorded a drastic increase in horizontal acceleration forces along the X-axis, rising from a baseline of 1.47 g without arms to 10.25 g with arms, and peaking at 12.88 g with the run-up. This nine-fold increase in horizontal force illustrates the massive momentum transfer required to elevate the center of mass. However, this force generation induces a significant horizontal displacement, observed in the video as a forward drift of 35.61 centimeters for the static arm swing and 57.20 centimeters for the run-up jump.

3.3 Synthesis and implications

The increase in force measured by the accelerometer and the improvement in height measured by Kinovea are two sides of the same physical law, the impulse:

The rapid and coordinated arm movement generates an additional vertical impulse. This increased impulse translates into a higher acceleration peak (quantified by the code) and, ultimately, a greater maximal take-off velocity (V0), thereby ensuring the better performance in height and flight time measured by Kinovea.

4 Critical aspects and improvements

Critical evaluation of our experimental protocol reveals significant methodological limitations, particularly in data acquisition and instrumentation selection. The video analysis using Kinovea would have been more accurate if the camera had been stabilized on a tripod and a crosshair marker had been added to the floor, two measures that would have minimized perspective error bias and facilitated calibration for video superimposition. More critically, the Axivity AX3 accelerometer used was not suitable for quantifying the most intense peak power of the jump, as the signal reached saturation on certain axes for jumps with arms and momentum. This dynamic range limitation prevents the recording of true maximum force (Fmax) and reduces the reliability of the calculated acceleration ratios, requiring a sensor with a higher measurement range for future studies.

5 Conclusion

The accelerometry data confirmed that the peak acceleration during the push-off phase was drastically increased, nearly seven times higher (ratio 6.98), when the arms were used. This acceleration is a direct proxy for the net vertical force exerted against the ground, consistent with the fundamental principle of dynamics (F = m * a). The increased acceleration confirms that the coordinated arm motion generates the necessary additional vertical impulse.

This project successfully achieved its objective by correlating dynamic and kinematic measurements of the vertical jump, confirming the significant and measurable contribution of the arm swing and run up to performance.

The kinematic analysis provided clear evidence of hierarchical improvement. The jump with arms reached 55.71 cm, representing an increase of 10.93 cm, and exhibited a longer flight time of 0.65 s compared to the jump without arms which measured 44.78 cm and 0.57 s. The inclusion of a run up further maximized this performance, reaching a peak height of 63.32 cm with a flight time of 0.72 s. This performance gain is directly explained by the dynamic analysis.

The accelerometry data confirmed that the peak acceleration during the push-off phase drastically increased, nearly seven times higher (ratio 6.98), when the arms were used. This acceleration peaked at approximately 8.77 times higher, or 12.88 g, during the jump run up. This massive horizontal acceleration confirms that the coordinated arm motion generates necessary momentum. This acceleration is a direct proxy for the net vertical force exerted against the ground, consistent with the fundamental principle of dynamics (F = m * a). The increased acceleration confirms that the coordinated arm motion generates the necessary additional vertical impulse. Crucially, Kinovea visualized the consequence of this horizontal force as the jumper exhibited a forward drift of 35.61 cm with static arms and 57.20 cm with a run up, proving that maximal vertical impulse requires the management of significant horizontal inertia.

In synthesis, the data demonstrates a clear cause and effect relationship. The increased acceleration measured by the wrist sensor is the biomechanical cause that leads to a higher take off velocity. This results in the greater jump height measured by Kinovea and is validated by the parabolic trajectory observed. The combined methodology confirms that optimizing intersegmental coordination is a key determinant of maximal vertical impulse production.

References

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