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Biomechanical Analysis of Elite Triple Jump Performance among Palestinian National Team Athletes

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Abstract

This study aimed to analyze the biomechanical performance characteristics of elite triple jumpers from the Palestinian national athletics team. The analysis focused on evaluating key kinematic variables such as jump phase distances, center of mass (COM) velocities, take-off angles, stiffness indices, and ground contact dynamics across the hop, step, and jump phases. The findings provide valuable insights into the efficiency of movement execution and highlight performance differentials between athletes, which can be instrumental for refining coaching strategies and optimizing athlete development.

Keywords

Triple Jump, biomechanical Analysis, Performance Indicators, Palestinian Athletics Team, Ground Reaction Force, Stiffness Index

ملخص

هدفت هذه الدراسة إلى تحليل خصائص الأداء البيوميكانيكية للاعبي الوثب الثلاثي المتميزين في المنتخب الوطني الفلسطيني لألعاب القوى. ركز التحليل على تقييم المتغيرات الحركية الرئيسية، مثل مسافات مراحل القفز، وسرعات مركز الكتلة (COM)، وزوايا الانطلاق، ومعاملات الصلابة، وديناميكيات التلامس الأرضي خلال مراحل القفز والخطوة والوثبة. تقدم النتائج رؤى قيّمة حول كفاءة تنفيذ الحركة، وتُبرز فروق الأداء بين الرياضيين، مما يُسهم في تحسين استراتيجيات التدريب وتحسين تطورهم.

الكلمات المفتاحية: الوثب الثلاثي، التحليل البيوميكانيكي، مؤشرات الأداء، المنتخب الوطني الفلسطيني لألعاب القوى، قوة رد فعل الأرض، معامل الصلابة

Introduction

Biomechanics is a foundational science within physical education and sport that provides tools for analyzing movement to improve performance and minimize injury. As highlighted by Abdel-Moneim et al. (1979) and Abdel-Basir (1998), understanding the biomechanical parameters of athletic performance facilitates informed coaching decisions and technical refinements. Biomechanical research in jumping events, particularly the triple jump, has historically contributed significantly to the development of technical models and performance enhancement strategies. Notably, Kilani et al. (1986) presented a pioneering kinematic analysis of an elite female triple jumper, emphasizing the importance of angular momentum control and inter-phase coordination. Building on such foundational work, Al-Kilani and Kilani (1993) proposed an optimization model for triple jump performance that demonstrated how mechanical variables could be manipulated to maximize distance and minimize performance loss across phases.

The triple jump is one of the most complex athletic events due to its integration of three consecutive phases: hop, step, and jump. The athlete must maintain maximal horizontal velocity while producing sufficient vertical force, a challenge requiring precise coordination and biomechanical efficiency (Coh, 2011; Hutt, 1988).

This study investigates the kinematic indicators of elite Palestinian triple jumpers, assessing variables such as phase distances, COM dynamics, take-off angles, and stiffness indices. It aims to offer a biomechanical model that supports training and performance evaluation. the kinematic indicators of elite Palestinian triple jumpers, assessing variables such as phase distances, COM dynamics, take-off angles, and stiffness indices. It aims to offer a biomechanical model that supports training and performance evaluation.

Objectives

1. To identify and evaluate key kinematic variables of elite Palestinian triple jumpers.
2. To compare these variables with those established for high-performance athletes globally.

Research Questions

1. What are the biomechanical characteristics of triple jump performance among elite Palestinian athletes?
2. How do these characteristics compare with global benchmarks for elite performance?

Methodology

Study Design

A descriptive biomechanical analysis using two-dimensional video analysis was employed.

Participants

Three elite male triple jumpers from the Palestinian national team participated. Basic anthropometric data are presented in Table 1.

Table 1. Basic Anthropometric Data

Name	Age (yrs)	Weight (kg)	Height (cm)	Leg Length (cm)	BMI (kg/m^2)	Best Performance (m)
Abdulrahim Shoman	24	65	178.1	94.3	20.5	13.10
Fahd Samreen	22	78	186	98.5	22.5	13.40
Mohammed Hoshiyah	21	72	182	96.4	21.7	13.60

Tools and Equipment

- Three high-speed Sony video cameras
- Dartfish Team Pro 2023 software
- Standardized calibration frame (1x1 meter)
- Measuring tape, cones, tripods
- PC with analysis software

Biomechanical Variables Measured

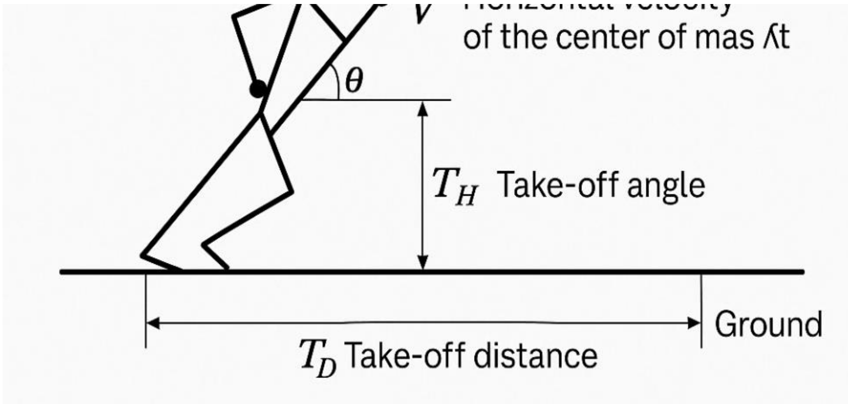

Figure 1. Key Performance Indicators of the Take-off Phase

Adapted from Jasminan Vaseekaran et al. (2021)

- **V**: Horizontal velocity of the center of mass at take-off
- **θ**: Take-off angle
- **T_H**: Height of the center of mass at the moment of take-off
- **T_D**: Take-off distance

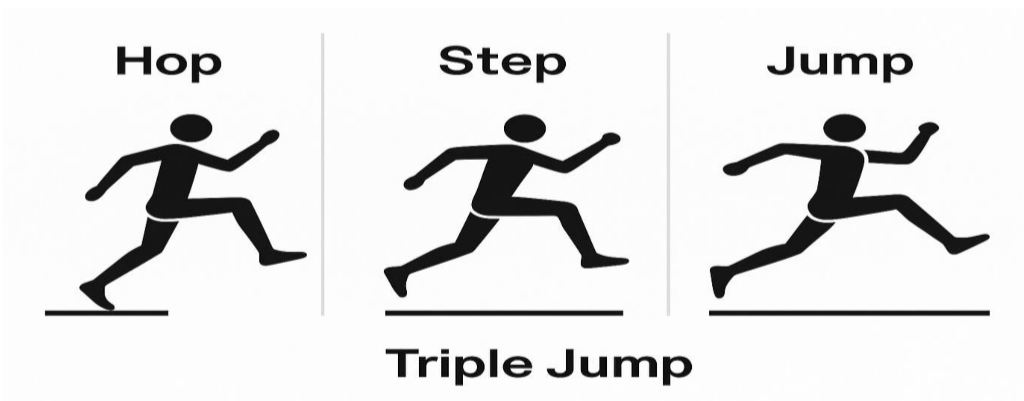

Figure 2. phases of the triple jump

- Phase distances (hop, step, jump)
- COM velocities (horizontal & vertical) during take-offs
- Take-off angles
- Flight and ground contact times
- Ground Reaction Force (Fmax)
- Vertical displacement of COM (Delta Yc)
- Stiffness Index (K vert)

Data Analysis and Formulas

1. **Resultant Ground Reaction Force (Fmax):**
   Fmax=mgπ(tf/tc)+12F_{max} = \frac{mg\pi(t_f/t_c) + 1}{2}
2. **Vertical Stiffness (K_vert):**
   Kvert=FmaxΔYcK_{vert} = \frac{F_{max}}{\Delta Y_c}
3. **Vertical Displacement of COM (ΔYc\Delta Y_c)**:
   ΔYc=Fmaxtc2mπ2+gtc28.3\Delta Y_c = \frac{F_{max} t_c^2}{m \pi^2} + g \frac{t_c^2}{8.3}

Results

Key biomechanical variables are summarized below.

Table 2. Descriptive Statistics of Biomechanical Variables

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Performance Result (m)	3	13.10	13.60	13.37	0.25
Total Hop Distance (m)	3	4.86	4.98	4.92	0.06
Total Step Distance (m)	3	3.44	3.92	3.65	0.25
Total Jump Distance (m)	3	4.70	4.89	4.80	0.10
COM Height at Take-off (Hop) (m)	3	1.11	1.22	1.18	0.06
COM Height at Take-off (Step) (m)	3	1.00	1.13	1.08	0.07
COM Height at Take-off (Jump) (m)	3	1.09	1.11	1.10	0.01
COM Horizontal Velocity at Take-off (Hop) (m/s)	3	8.16	8.51	8.38	0.19
COM Vertical Velocity at Take-off (Hop) (m/s)	3	1.98	2.10	2.02	0.07
COM Horizontal Velocity at Take-off (Step) (m/s)	3	7.62	8.40	8.11	0.42
COM Vertical Velocity at Take-off (Step) (m/s)	3	1.43	1.69	1.59	0.14
COM Horizontal Velocity at Take-off (Jump) (m/s)	3	7.49	8.15	7.74	0.36
COM Vertical Velocity at Take-off (Jump) (m/s)	3	1.90	2.00	1.94	0.05
Take-off Angle during Hop Flight (°)	3	15.40	16.50	15.80	0.61

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Take-off Angle during Step Flight (°)	3	0.16	16.70	10.85	9.27
Take-off Angle during Jump Flight (°)	3	17.50	18.40	18.03	0.47

Table 3. Average Phase Contribution to Total Performance

Phase	Contribution %
Hop	36.80%
Step	27.30%
Jump	35.90%

Table 4. Individual Phase Contribution by Athlete

Athlete	Performance (m)	Hop (%)	Step (%)	Jump (%)
Athlete 1	13.10	37.10%	26.26%	36.64%
Athlete 2	13.40	36.80%	26.70%	36.50%
Athlete 3	13.60	36.61%	28.82%	34.57%
Total	100%	100%	100%	100%

Table 5. Detailed Biomechanical Metrics by Athlete

Variable	Abdulrahim Shoman	Fahd Samreen	Mohammed Hoshiyah
Performance (m)	13.10	13.40	13.60
Hop Distance (m)	4.86	4.93	4.98
Step Distance (m)	3.44	3.58	3.92
Jump Distance (m)	4.80	4.89	4.70
Avg. Velocity in Final Step (m/s)	8.37	8.60	8.60
COM Height at Take-off (Hop) (m)	1.11	1.22	1.21
COM Height at Take-off (Step) (m)	1.00	1.13	1.10
COM Height at Take-off (Jump) (m)	1.11	1.11	1.09
Horizontal Velocity at Take-off (Hop) (m/s)	8.16	8.48	8.51
Vertical Velocity at Take-off (Hop) (m/s)	1.99	1.98	2.10
Horizontal Velocity at Take-off (Step) (m/s)	7.62	8.30	8.40
Vertical Velocity at Take-off (Step) (m/s)	1.43	1.65	1.69
Horizontal Velocity at Take-off (Jump)	7.49	7.58	8.15

Variable	Abdulrahim Shoman	Fahd Samreen	Mohammed Hoshiyah
(m/s)			
Vertical Velocity at Take-off (Jump) (m/s)	1.93	2.00	1.90
Take-off Angle (Hop) (°)	15.4	15.5	16.5
Take-off Angle (Step) (°)	15.7	16.1	16.7
Take-off Angle (Jump) (°)	17.5	18.4	18.2
Ground Contact Time (Hop) (s)	0.134	0.150	0.150
Ground Contact Time (Step) (s)	0.150	0.184	0.167
Ground Contact Time (Jump) (s)	0.134	0.184	0.183
Fmax Hop (N)	4609.08	4804.80	4560.86
Fmax Step (N)	2108.77	2722.28	3299.84
Fmax Jump (N)	5729.60	5118.16	4847.21
Delta Yc Hop (m)	0.15	0.17	0.17
Delta Yc Step (m)	0.10	0.16	0.16
Delta Yc Jump (m)	0.18	0.27	0.27
K vert Hop (kN/m)	30.54	28.62	26.54
K vert Step (kN/m)	20.78	16.90	20.17
K vert Jump (kN/m)	31.44	19.21	18.00

Discussion

The analysis revealed notable consistency in biomechanical parameters among the three elite triple jumpers, particularly in the distribution of distance across the three phases of the jump. The hop and jump phases each contributed approximately 36% to the overall jump distance, while the step phase accounted for a slightly lower contribution (~27%). These findings are consistent with previous literature, which has established the hop and jump phases as being more force-dependent and length-contributing due to greater involvement of propulsion mechanics and optimal take-off technique (Allen et al., 2013; Yu, 1999).

The horizontal and vertical velocities of the center of mass (COM) at take-off for each phase remained within globally recognized performance benchmarks. For instance, Hussain et al. (2022) and Vaseekaran et al. (2021) have reported similar take-off angles and velocity ranges for elite jumpers, underscoring the validity of the performances observed in this study. Despite general alignment with elite norms, variability was noted in the step phase, particularly in terms of COM velocity losses and longer contact times. This could reflect neuromuscular control limitations or suboptimal synchronization of upper- and lower-body motion, as also discussed in Perttunen et al. (2000).

One of the most insightful findings relates to vertical stiffness (K vert), a key determinant of how effectively athletes absorb and reutilize ground reaction forces. Abdulrahim Shoman demonstrated higher K vert values during the jump phase, indicating superior elastic energy storage and return. This biomechanical efficiency aligns with the spring-mass model proposed by Butler et al. (2003), where optimal stiffness values enhance performance by minimizing energy dissipation during ground contact and maximizing propulsion. Conversely, athletes with lower K vert values may experience excessive joint flexion or delayed muscle activation, leading to energy losses.

The results also underscore the importance of training programs that target stiffness modulation and take-off timing optimization, particularly during the transition from step to jump. Enhanced coordination between limb swing dynamics and ground force application—highlighted by Hay (1985) and Coh et al. (2011)—is essential to reduce braking forces and preserve horizontal momentum.

Collectively, these insights suggest that while general biomechanical efficiency is evident among the athletes, targeted improvements in phase transitions and stiffness control could yield further performance enhancements.. The step phase consistently accounted for slightly less contribution (~27%).

COM velocities and take-off angles among the athletes closely align with global benchmarks (Hussain et al., 2022; Vaseekaran et al., 2021), though slight variability exists in step duration and velocity losses.

Stiffness indices (K vert) reveal differences in load absorption and elastic energy return, with Abdulrahim Shoman demonstrating higher efficiency during the jump phase.

Conclusion

The current study highlights that elite Palestinian triple jumpers demonstrate biomechanical performance characteristics generally consistent with international norms. The distribution of distance across the three phases—hop, step, and jump—aligns with global findings, and the observed COM velocities, take-off angles, and stiffness indices confirm a high level of technical proficiency. However, variability in step-phase dynamics and energy losses suggests room for optimization, particularly in inter-phase transitions and elastic energy utilization. This reinforces the value of regular biomechanical assessment as a feedback mechanism for individualized training interventions.

Limitations of the Study

Despite its valuable findings, this study has several limitations. First, the small sample size (n = 3) limits the generalizability of the results. Second, the analysis was conducted in a two-dimensional framework, which may not capture the full complexity of three-dimensional movement. Third, environmental and contextual factors (e.g., surface conditions, psychological state) were not controlled, which could have influenced performance.

Recommendations

- Implement individualized stiffness and plyometric training programs.
- Utilize regular biomechanical evaluations to adjust technical models.
- Enhance upper-limb coordination for better propulsion timing.

Prospective and Perspective Future Research

Future studies should include larger sample sizes and incorporate three-dimensional motion capture technologies for more comprehensive biomechanical insights. Expanding the participant pool to include athletes from varying performance levels and age groups could enhance understanding of developmental trajectories in triple jump performance. Longitudinal studies evaluating the impact of specific training interventions—particularly those targeting stiffness modulation, plyometric adaptation, and arm-leg coordination—are also encouraged. Finally, comparative research between genders and across nations could provide broader insights into performance determinants and support the development of culturally and regionally tailored coaching models. that are generally consistent with international norms. Specific refinements, particularly in minimizing velocity losses and optimizing stiffness response, can contribute to performance enhancements.

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