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Article

Technical analysis and simulation of dance movements based on biomechanical theory

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Abstract: Dance movements are a form of expressive physical activity that communicates emotions, stories, and cultural significance through the rhythmic motions of the body. Viewed through the lens of biomechanical theory, it offers a unique understanding of the body's physical actions and interactions in space. Biomechanics, the science of movement explains the mechanical principles of human motion, including forces, motion, and body structure. It aims to analyze the biomechanical principles underlying various dance movements, including forefoot (FT) landing, entire foot (ET) landing, single-leg landing, bounce, rock step, and side chassé step. A total of 42 dancers performed these movements in the jive and cha-cha, synchronized with corresponding music. Data were collected using a Vicon motion capture system and pressure sensors, which were uploaded into the OpenSim simulation model to create musculoskeletal models. Statistical Parameter Mapping (SPM) analysis was used to assess biomechanical differences across various dance movements. Depending on the data distribution, ANOVA, multiple regression analysis, and paired t-tests were employed to examine muscle forces involved in the different dance movements. The biomechanical analysis revealed that FT landing increased ankle inversion and instability, while ET landing provided greater stability. Single-leg landing generated higher forces, while the bounce movement was energy-efficient with increased plantarflexion. It may also increase the risk of injury due to higher forces. With careful technique to avoid overloading and injury, these findings may be used in dance training by implementing controlled ET landings for stability and balance, as well as single-leg landings to increase force absorption and build lower limb muscles. The side chasse step and rock step required greater lateral stability, with higher muscle activation in the hip and ankle joints. In conclusion, the biomechanical analysis highlights significant differences in muscle activation, joint angles, and stability across the dance movements.

Keywords: biomechanical theory; dance movements; statistical parameter mapping (SPM); OpenSim; single-leg landing

1. Introduction

The dance steps offer main structures for interacting with emotional messages, story themes, and stylistic components. Through the elaborate interplay of body dynamics, dancers can convey difficult feelings and stories that resonate with viewers on a profound level. Physical actions form a wide range that contains basic and complicated movement patterns [1]. From easy steps to expand sequences, every step contributes to the whole story, allowing dancers to convey messages that may be difficult to articulate with words. Every dance style concentrates on exact steps that both stem from its unique artistic background and express different emotional messages. Such movements are performed at different levels of strength and speed or with different degrees of exactness. This variability allows dancers to adapt their expressions based on the feel of the song or the background of the performance, developing the narrating aspect of their art. The movement sequence requires synchronized action between the legs, torso, and arms as well as the head [2]. This coordination is necessary for creating visually attractive performances, where all body parts work in harmony to make a unified expression. The earth language of expression is away from words for dance movements that could be defined by hip-hop's sharpness, salsa's rhythmic patterns, and ballet's graceful fluidity. These different features not only describe each style but also elicit correct emotional responses from the audience, making dance a worldwide form of communication. Technical aspects become a part of the dance steps to perform the body movement concerned in learning to dance. Dancers should master these technical parts to make sure that their movements are precise and impactful, which eventually improves the whole performance. This can range from timing, balance, alignment, and spatial awareness, among other things that can create a difference in the final excellence of performance [3]. All of these elements play a vital role in ensuring that dancers can perform with grace and confidence, which is essential for attracting their audience. Dancers train to improve the strength, control, and flexibility of their bodies so dancers can perform difficult movements with ease and fluidity. This rigorous training not only builds physical capabilities but also fosters mental discipline and flexibility, sinnificant qualities for any performer. During performance, the dancer interacts with musical beats through their body motions while their technical ability and the music lead their movements. This interaction creates a sparkling relationship between the music and the dancer, where every rhythm and beat influences the flow of movement, resulting in a delightful spectacle. The artistic combination of these elements generates an energetic dance expression that creates an emotional and aesthetic connection with the audience [4].

Biomechanics uses morality from engineering and physics to examine the mechanics of human motion. This interdisciplinary approach allows for a profound insight into how forces and movements interact, providing precious insights into the effectiveness and efficiency of various physical activities. The request of dance allows biomechanics theory to examine dancers' body movements and motion interactions with space elements as well as physical body responses to gravitational friction, momentum, and forces [5]. By analyzing these interactions, researchers can recognize optimal movement patterns that improve performance while minimizing the danger of injury. The effective coordination of all human body components—including bones, muscles, ligaments, and joints—functions as a unified system during difficult dance movements. Application in dancing performance will teach the performers to place their bodies to better use and make optimal use of actions [6]. Through targeted training and biomechanical analysis, dancers can learn to harness their physical capabilities more efficiently, leading to developed performance results. An understanding of how the body mass is distributed, the angles of the joints, and the relationship between muscles and bones will get aesthetically beautiful and physiologically sustainable movement.

The dancing formation contains three basic elements: alignment, posture, and body control. These can be enhanced with the request of biomechanical concepts in examining the space motion of the body [7]. Biomechanical theory is also based on alignment and posture. Proper alignment ensures that forces are distributed evenly throughout the body to minimize strain and maximize the body's potential. Dancers who maintain proper posture can have more control over their movements and prevent overuse injuries [8]. Incorporating biomechanical training into regular practice can significantly reduce the incidence of injuries, allowing dancers to perform at their best for longer periods. Biomechanical theory in dance can limit creativity because it's too focused on physical constraints that reduce expressive freedom. While biomechanics provides essential insights into movement efficiency, it is important to strike a balance between technical precision and artistic expression. It often focuses on the efficiency and form of movement rather than emotional or artistic qualities. It intended to examine the biomechanical concepts that underlie several dance moves, such as side chassé step, bounce, rock step, single-leg landing, FT landing, and ET landing. By analyzing these specific movements, dancers can gain a better understanding of how to execute them with both technical skill and artistic flair.

The structure is as follows. Literature is discussed in Section 2. The methodology is covered in Section 3. Results are shown in Section 4. The discussion is provided in Section 5. Section 6 concludes with a few suggestions on the scalability of the system and potential future developments.

2. Related works

Sports biomechanics experiment techniques to examine how players rotate during samba dance were analyzed in [9]. The advanced motion capture technology was utilized and force plates were used to provide a comprehensive analysis of the dancers' rotational mechanics, offering insights into how these movements are executed in real-time. It blended the rotational features of samba dancing with an understanding of biomechanics. By integrating these two fields, the research aimed to uncover the underlying principles that govern effective movement in samba, which is characterized by its dynamic and rhythmic rotations. The results showed no significant differences between the test and control groups in step size, walking speed, relative speed, and number of times spent in foot contact, or length, which also demonstrated that foot pressure indicators exhibited regularly across all action phases. These findings suggest that regardless of the dancers' skill levels, fundamental biomechanical principles remain consistent, highlighting the importance of proper technique in achieving optimal performance.

The connection between judging ratings and the opposite body movement executed by dance sport athletes performed during the Viennese waltz was examined in [10]. Focused on understanding how the harmonization of body movements influences the whole aesthetic and technical assessment of dance performances. In the waltz, six pairs with advanced dancing skills and six pairs with intermediate skills executed three natural turns. The inclusion of both skill levels permitted a comparative investigation, shedding light on the nuances that distinguish advanced dancers from their intermediate counterparts. A widget that calculated triaxial rotational angular velocities was used by worldwide judges to evaluate the trials. The results showed an extensive correlation between judging ratings and the difference in angular rotation velocity between the pelvic girdle and thoracic spine. The correlation emphasizes the significance of body alignment and rotational coordination in achieving high performance scores in competitive dance.

The effect of foot position on professional ballet dancers' ankle joint mechanics and vertical ground reaction forces was analyzed in [11]. To aim to discover how different foot placements impact the biomechanics of ballet steps, mainly during landings, which are serious for preventing injuries and maintaining balance. The findings showed that the ankle power necessary for jump landings in the slanting plane was double that of any other position, representative that ankle mechanics had the most influence on the frontal and transverse planes. Based on the outcomes, exact exercises must be completed to strengthen local ankle tissues and restore the ankle's range of motion. Executing targeted training regimens can help dancers improve their performance capabilities while reducing the risk of injuries connected with inadequate ankle support.

The experienced female dancers sauté landings before and after physical exhaustion were assessed in [12]. Following exhaustion, dancers displayed reduced peak metatarsophalangeal joint extension and enlarged mediolateral ankle eversion, external rotation, pelvic excursion, center of mass displacement and peak knee absorption. These changes point out a shift in the biomechanics of landing, which can affect both performance quality and injury risk. It also demonstrated a softer landing technique, which resulted in a minor peak vertical ground response force. Improved unusual strength and endurance could assist dancers in achieving performance-related aesthetic requirements. By developing these physical attributes, dancers can enhance their landing technique, thereby improving their whole performance and reducing the probability of injuries.

The incidence of Muscular Skeletal Disorder Episodes (MDEs) among dancers in relation to movement competency, Transversus Abdominis Activation (TrA), and hip strength was analyzed in [13]. Sought to recognize risk factors for MDEs, which are ordinary among dancers due to the physical demands of their art. A weekly electronic record was used to recruit and assess 118 dancers. It was demonstrated that minor TrA, stronger hip abductor and external rotator capacity, and lower hip external rotation capacity significantly reduced the incidence of MDEs. There was no apparent relation between movement competence and MDEs. Suggested that even skilled dancers may be at risk for injuries if dancers lack specific strength or steadiness, emphasizing the need for targeted training programs.

The side chasse step and bounce step of the next landing point in Jive were investigated in [14] for the lower member biomechanics. Focused on understanding the biomechanics of specific dance movements, which is essential for both performance enhancement and injury prevention. Using the same music during the data-collecting period, thirteen female Latin dancers who were leisure dancers participated. The results showed substantial differences in lower limb biomechanics between the two phases. These differences highlight the unique demands placed on the body by different dance steps, informing training and rehabilitation practices. It was essential to strengthen the muscles in the lower limbs, such as the quadriceps, gastrocnemius, and tibialis, to prevent foot issues and balance joint strength. Incorporating strength training for these muscle groups can enhance performance and reduce the risk of injuries associated with specific dance movements.

According to court sports, footwear and flooring could assist in lessening injuries to the lower extremities, as demonstrated in [15]. Since ballet and contemporary dancers and learners cannot wear shoes, the only external component that could assist in absorbing stress was flooring. The type of flooring can significantly influence the forces experienced during dance, affecting both performance and injury rates. The average peak muscle amplitude for the medial gastrocnemius and soleus muscles increased during sautéing on a dance floor with low stiffness. The suggestion is that softer surfaces may require greater muscle activation to maintain stability and control. Through muscular velocity adjustment, the variation in force absorption could lower injury rates in dance.

3. Methodology

Dance moves are physical acts that are done to music and use a variety of approaches to convey emotion and rhythm. 42 dancers presented jive and cha-cha skills, consisting of FT landing, ET landing, single-leg landing, bounce, rock step, and side chassé step. By using Vicon motion capture and pressure sensors, data was acquired and then further analyzed with the help of OpenSim musculoskeletal models. For the investigation of biomechanical differences, SPM was used. ANOVA, multiple regression analysis, and paired *t*-tests have been used to observe the muscle forces across the various dance moves depending on the data distribution.

3.1. Sample data

The selected movements of the jive and cha-cha were performed by 42 dancers, 21 males and 21 females. Vicon (the system is well known for its excellent accuracy in registering body motions and joint angles). Motion capture technology was used to record the dancer’s joint angles and body movements in three dimensions. Pressure sensors were also placed on the dancer’s feet to measure the forces exerted during foot-ground contact. The motion and force data were uploaded into the OpenSim (The model, used a generic musculoskeletal model with standard muscle activation strategies and joint constraints) simulation model to create musculoskeletal models for the estimation of muscle forces and joint mechanics for each movement, is demonstrated in **Figure 1**.

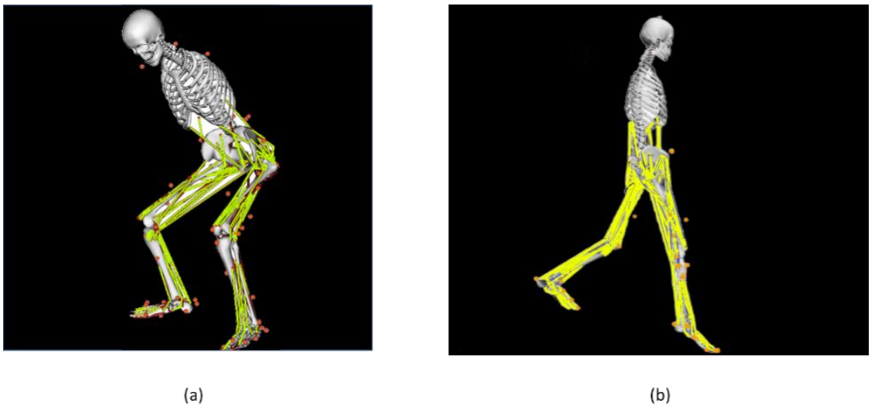

Figure 1. Biomechanical dance movement analysis using OpenSim musculoskeletal models, **(a)** entire foot landing; **(b)** single leg landing.

Participants details

The 42 dancers were split equally between both genders, with 21 of them being male (50%) and 21 being female (50%). 28.57% of participants were in the 18–22 and 28–32 age groups, while 42.86% were in the 23–27 age group. The participants ranged in age from 18% to 32.9%. 52% of the population was over 180 cm, 42.86% was between 161 and 170 cm, 23.81% was between 171 and 180 cm, and 23.81% was between 150 and 160 cm in height. Of the total weight, 33.33% fell into the 50–60 kg range, 47.62% into the 61–70 kg range, and 19.05% into the 71–80 kg range. Dance experience varied among participants: 23.81% had 3–5 years of experience, 23.81% had more than 10 years, and 52.38% had 6–10 years. **Table 1** and **Figure 2** show the demographic data.

Table 1. Demographic data.

Variables	**Categories**	**Frequency (*n*)**	**Percentage (%)**
Gender	Male	21	50%
	Female	21	50%
Age group (years)	18–22	12	28.57%
	23–27	18	42.86%
	28–32	12	28.57%
Height (cm)	150–160	10	23.81%
	161–170	18	42.86%
	171–180	10	23.81%
	Above 180	4	9.52%
Weight (kg)	50–60	14	33.33%
	61–70	20	47.62%
	71–80	8	19.05%
Years of dance experience	3–5 years	10	23.81%
	6–10 years	22	52.38%
	More than 10 years	10	23.81%

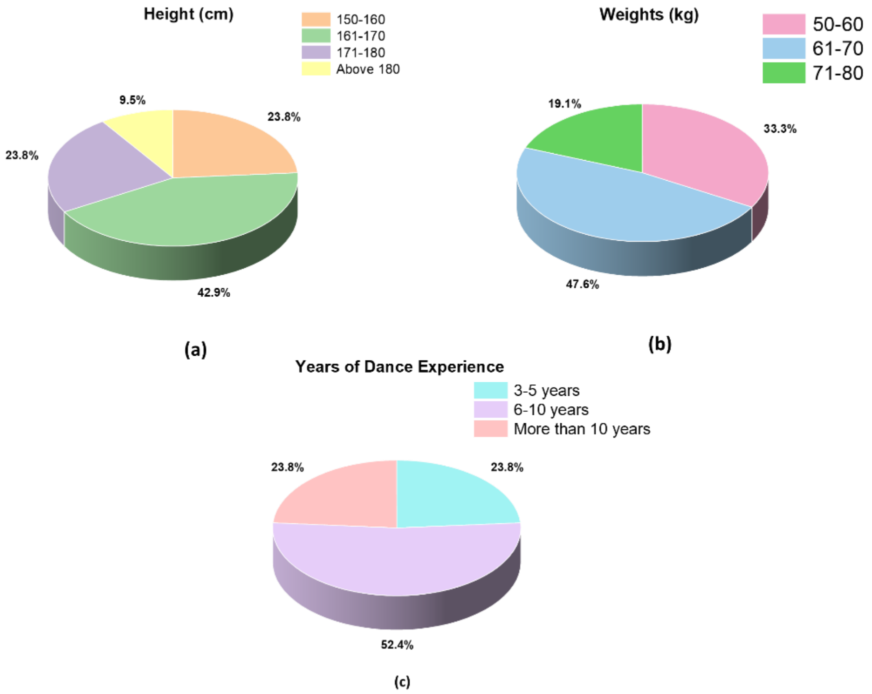

Figure 2. Demographic data, **(a)** height (cm); **(b)** weight (kg); **(c)** years of experience.

3.2. Selection and analysis of Jive and Cha-Cha dancers

42 dancers were selected from a pool of participants, who could perform the jive and cha-cha dances well, and each dancer was well-equipped with the techniques and could perform the required movements. Selection criteria included prior training in competitive or performance-based dance, age group, and the ability to synchronize their movements with music. Dancers were asked to perform movements under controlled conditions for consistency across data collection. The data were processed and analyzed using SPM, which is a technique used for the analysis and comparison of continuous data at multiple time points or conditions to determine biomechanical differences through all the different dance movements.

3.3. Method of data analysis

IBM SPSS version 29.0 was used to examine the biomechanical principles of dance motions, such as the FT landing, ET landing, single-leg landing, bounce, rock step, and side chassé step. Multiple regression analysis, paired *t*-tests, and ANOVA were some of the statistical methods that were applied. ANOVA was used to determine the differences between related groups. Paired *t*-tests were applied to assess discrepancies between the numbers of dance motions. Regression analysis was utilized to examine the relationship between variables, where different biomechanical elements affect dance performance and movement dynamics.

4. Result

The biomechanical data for the dancers was investigated using paired *t*-tests, multiple regression analysis, and ANOVA. The differences in joint angles, stability of different dance steps, and muscle forces, like ET and FT landings, were calculated by ANOVA. Biomechanical variables between particular steps were also compared to show the differences in force generation and steadiness by the paired *t*-test. Multiple regression analysis has been utilized to decide the interrelationships between different factors, such as muscle activation, movement competence, and joint angles. Thus, all these statistical tools have contributed to an understanding of how these various elements contribute toward influencing the final performance of dancing.

- ANOVA

Table 2 and **Figure 3** display an ANOVA analysis that looks at how different dance motions affect a particular outcome. For each movement, the Sum of Squares (SS), Degrees of Freedom (df), Mean Square (MS), *F*-statistic (ANOVA analysis's *F*-statistics, that evaluate the effects of various dancing moves, are displayed on the *Y*-axis in **Figure 3**. There is no need for particular units because *F*-statistics are unitless), and *p*-values are given. With SS = 2500, MS = 2500, $F = 16.4$, and $p = 0.0005$, the single-leg landing has the greatest impact and is statistically significant. With SS = 2200, MS = 2200, $F = 14.3$, and $p = 0.001$, FT landing following in second, it demonstrates substantial significance as well. Side chassé step has a similar effect with SS = 2000, MS = 2000, $F = 13.0$, and p = 0.003, but rock step has SS of 2100, MS of 2100, $F = 13.6$, and $p = 0.002$. With an SS of 1400, MS of 1400, $F = 9.1$, and $p = 0.005$, bounce has an insufficient but significant impact. Finally, ET landing maintains statistical significance (SS = 1000, MS = 1000, $p = 0.02$) despite having the lowest *F*-statistic ($F = 6.5$). Every dance action appears to have a substantial influence on the observed variance, with single-leg landing having the impact, according to the low *p*-values (< 0.05) for all moves.

Table 2. Values for ANOVA test.

Variables	SS	df	MS	*F*-statistic	*p*-value	Cohen's *d*	η^2
FT landing	2200	1	2200	14.3	0.001	1.01	0.53
ET landing	1000	1	1000	6.5	0.02	0.67	0.34
Single-leg landing	2500	1	2500	16.4	0.0005	1.14	0.64
Bounce	1400	1	1400	9.1	0.005	0.83	0.45
Rock step	2100	1	2100	13.6	0.002	0.97	0.51
Side Chassé step	2000	1	2000	13.0	0.003	0.94	0.49

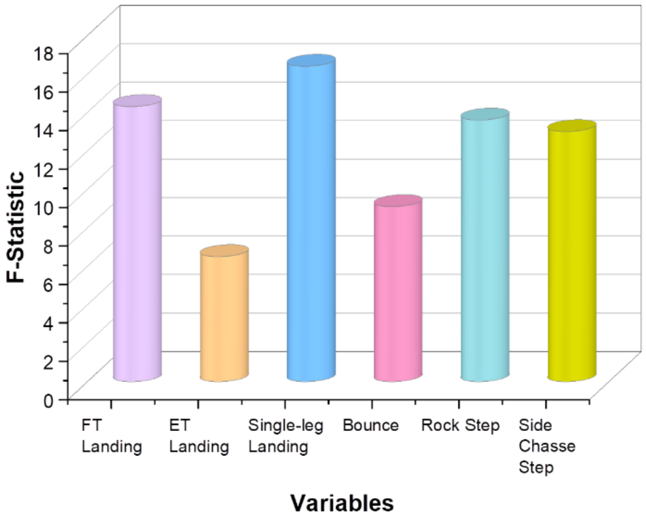

Figure 3. F-statistics performance in the ANOVA test.

- Paired t-test

The statistical data, including mean values (the mean is the average value measured for each dance movement or landing type, which may include variables like FT landing, ET landing, or other performance measures based on the research emphasis), standard deviations (SD), t-statistics, degrees of freedom $(\text{df} = 41)$, and p-values, are displayed in **Table 3** and **Figure 4** for the various landing and movement types. FT with a mean of 14.5 and an SD of 5.0, landing exhibits statistical significance, as evidenced by a t-statistic of 3.10 and a p-value of 0.004. With a t-statistic of 4.25 and a very significant p-value of 0.001, ET landing has a higher mean of $17.5(\text{SD} = 2.5)$. With a strong t-statistic of 5.30, a highly significant p-value of 0.0001, and the highest mean of $20.2(\text{SD} = 5.6)$ for single-leg landing. The lowest t-statistic (1.85) and non-significant p-value (0.075) are found for bounce, which has a mean of 10.1 and an SD of 2.3. With a t-statistic of 3.20 and a p-value of 0.003, rock step $(\text{mean} = 18.0, \text{SD} = 4.0)$ is statistically significant. Similarly, the side chassé step has a t-statistic of 3.15 and a p-value of 0.004, indicating significance, with a mean of 18.5 and an SD of 4.2. With the exception of bounce, the majority of motions show statistical significance $(p < 0.05)$, indicating significant variations in landing or movement performance across conditions.

Table 3. Paired t-test values.

Variable	Mean	SD	*t*-statistic	df	*p*-value
FT landing	14.5	5.0	3.10	41	0.004
ET landing	17.5	2.5	4.25	41	0.001
Single-leg landing	20.2	5.6	5.30	41	0.0001
Bounce	10.1	2.3	1.85	41	0.075
Rock step	18.0	4.0	3.20	41	0.003
Side Chassé step	18.5	4.2	3.15	41	0.004

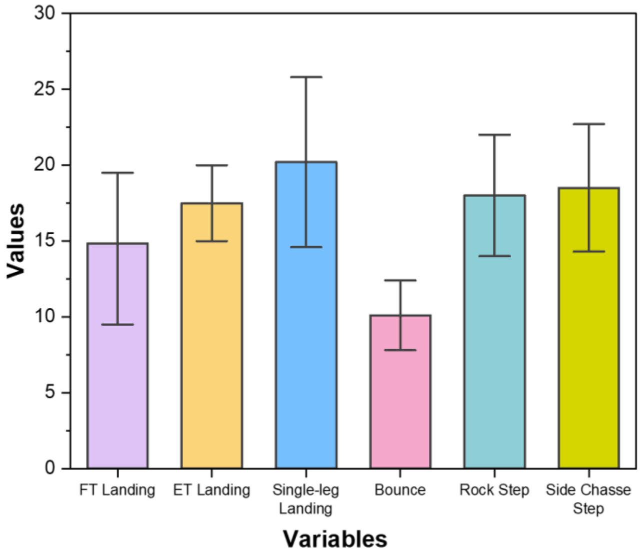

Figure 4. Mean and standard deviation performance in paired *t*-test.

- Multiple regression analysis

Table 4 and **Figure 5** display statistical findings, such as unstandardized coefficients (β), standard errors (SE), t-values, p-values, R^2, and adjusted R^2, for various landing and movement approaches. Strong predictive ability is demonstrated by FT landing's β of 1.80 (SE $= 0.50$), significant t-value of 3.60 ($p = 0.001$), and R^2 of 0.72. With an R^2 of 0.65 and a t-value of 1.67, ET landing has a lower β of 0.50(SE $= 0.30$), but it is not statistically significant ($p = 0.100$). With a significant t-value of $3.67(p = 0.001)$, an R^2 of 0.74, and the highest β of 2.20 (SE $= 0.60$), single-leg landing is a powerful predictor. Bounce has a significant t-value of 2.25 ($p = 0.026$), an R^2 of 0.69, and a β of 0.90 (SE $= 0.40$).The results for rock step are as follows: $\beta = 1.10$(SE $= 0.45$), $R^2 = 0.71$, and a significant $t -$ value of 2.44 ($p = 0.020$). A significant $t -$value of $2.73(p = 0.008)$, an R^2 of 0.73, and a β of 1.50(SE $= 0.55$) are all present in the side chassé step. Overall, ET landing is not statistically significant, but single-leg landing exhibits the most predictive power. Every other movement exhibits a moderate to great capacity for prediction.

Table 4. Values for multiple regression analysis tests.

Variable	***β***	**SE**	***t*-value**	***p*-value**	***R*²**	**Adjusted *R*²**
FT landing	1.80	0.50	3.60	0.001	0.72	0.68
ET landing	0.50	0.30	1.67	0.100	0.65	0.60
Single-leg landing	2.20	0.60	3.67	0.001	0.74	0.70
Bounce	0.90	0.40	2.25	0.026	0.69	0.64
Rock step	1.10	0.45	2.44	0.020	0.71	0.66
Side Chassé step	1.50	0.55	2.73	0.008	0.73	0.69

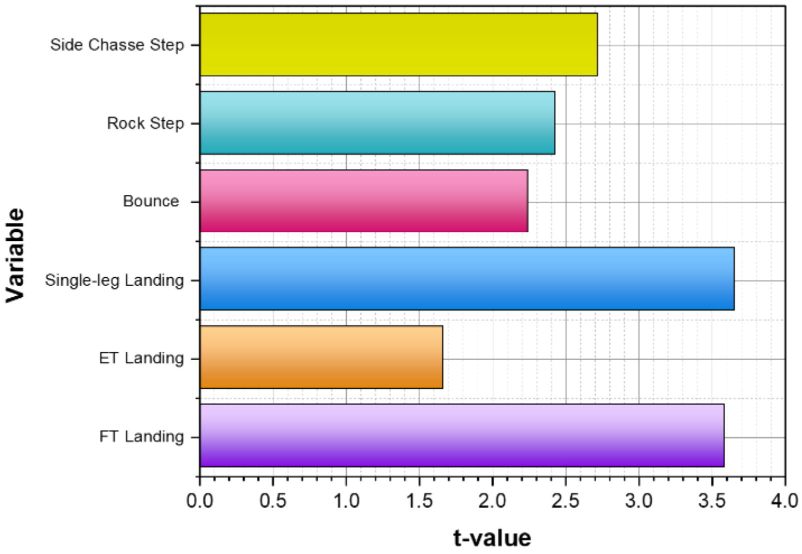

Figure 5. t-value performance in multiple regression test.

5. Discussion

The mechanical principles of motion, forces, and structure of the body are analyzed in dance movements based on biomechanical theory to improve performance, stability, and efficiency. This research is vital for understanding how dancers can optimize their movements to improve their whole efficiency on stage. In ANOVA, FT landing has an extremely significant effect with an F-statistic of 14.3 and a p −value of 0.001. Statistical outcomes point out that FT landing is a serious factor influencing performance results, suggesting that the method used in this landing is crucial for dancers. Because their p-values are less than 0.05, other factors such as Rock Step $(F = 13.6, p = 0.002)$ and single-leg landing $(F = 16.4, p = 0.0005)$ also have significant effects on the result. This reinforces the plan that namouras landing techniques contribute significantly to a dancer's performance and injury prevention. Additionally, significant impacts are indicated by the side chassé step $(F = 13.0, p = 0.003)$ and bounce $(F = 9.1, p = 0.005)$. These outcomes emphasize the significance of different dance movements and their biomechanical implications. Overall, each of the variables had important p-values, representative of their significance for the research. Paired t-test outcomes for different landing and movement activities are displayed. The force of the deviation from the mean is demonstrated by the p-value and t-statistic, where values less than 0.05 imply statistical significance. The single-leg landing yields a very significant result with a mean of 20.2, a $t-$statistic of 5.30, and a $p-$value of 0.0001. This suggests that the single-leg landing technique is mainly efficient and warrants further investigation for its application in training. Significant differences can be observed between ET landing $(\text{mean} = 17.5, p - \text{value} = 0.001)$ and FT landing $(\text{mean} = 14.5, p - \text{value} = 0.004)$. These differences indicate that variations in landing techniques can lead to substantial changes in performance outcomes. The "bounce" is not statistically significant $(\text{mean} = 10.1, p - \text{value} = 0.075)$. Bounce technique is commonly used; it may not contribute as effectively to performance as other techniques. The β for each variable is shown in the table together with their SE, t-

values, p-values, R^2, and adjusted R^2. Adjusted R^2 values range from 0.60 to 0.70, indicating significant correlations between the dependent variable and variables such as FT landing $(\beta = 1.80, p = 0.001)$, single-leg landing $(\beta = 2.20, p = 0.001)$, and side chassé step $(\beta = 1.50, p = 0.008)$. These coefficients further illustrate the strength of the relationships between the landing techniques and overall performance metrics. The model's percentage of variation explained is indicated by the R^2 values, with single-leg landing having the greatest value at 0.74. This high R^2 value signifies that the single-leg landing technique explains a substantial portion of the variance in performance, emphasizing its importance in dance biomechanics.

6. Conclusion

Dance moves are a type of expressive physical exercise that uses the body's rhythmic motions to convey feelings, stories, and cultural importance. Analyzing the biomechanical foundations of different dance moves, such as the FT, ET, single-leg, bounce, rock, and side chassé steps, is its goal. In the jive and cha-cha, 42 dancers executed these moves precisely with the appropriate music. A Vicon motion capture device and pressure sensors were used to gather data, which were entered into the OpenSim simulation model to generate musculoskeletal models. Biomechanical variations across different dancing moves were evaluated using the SPM technique. To investigate the muscle forces involved in the various dance moves, ANOVA, multiple regression analysis, and paired t-tests were used, depending on the data distribution. For ANOVA, the most statistically significant is the single-leg landing $(F = 16.4, p = 0.0005)$, which has the lowest p-value and the greatest F-statistic. Although the F-statistic and p-value are marginally smaller, the FT landing $(F = 14.3, p = 0.001)$ similarly demonstrates substantial significance. For the paired t-test, the single-leg landing $(t = 5.30, p = 0.0001)$ shows the strongest statistical significance with the highest mean (20.2) and the bounce has the lowest mean (10.1) and the least significance $(t = 1.85, p = 0.075)$. For multiple regression analysis, the single-leg landing with a high $\beta = 2.20$, a significant p-value (0.001), and an excellent adjusted R^2 of 0.70 is the strongest predictor for the dependent variable. It is difficult to simulate complicated human biomechanics accurately and analyze motion in real-time. Motion capture and artificial intelligence developments can improve accuracy, enabling customized choreography and rehabilitative applications. The future research will be given utilizing visual aids, such as effect size forest plots, to more clearly emphasize and facilitate the comprehension of the data by highlighting important findings from the statistical parameters (SS, df, β, etc.). Future research could consider revealing certain error margins or calibration methods to guarantee the accuracy of the data collected during motion analysis. Future studies may benefit from accounting for such variables by including them as covariates in the analysis or grouping participants based on experience or injury history to isolate their effects on the results.

Conflict of interest: The author declares no conflict of interest.

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