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The Triple Step in Recreational Swing Dancers: A Kinematic Analysis

MEREDITH D. WELLS†1, and FENG YANG‡1

1Department of Kinesiology and Health, Georgia State University, Atlanta, GA, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 15(1): 1492-1505, 2022. Swing dancing is gaining popularity, yet our biomechanical understanding of swing dance remains poor, creating barriers to the development of training protocols and evaluation of performances. This study aimed to determine whether dancing with or without a partner affects the lower extremity kinematics of the triple step, and if the kinematics differ among the three steps of the dance element. Eight recreational swing dancers completed three sets of rightward triple steps with and without a partner. The angles in the sagittal, frontal and transverse planes were determined for bilateral lower limb joints and pelvis based on the kinematics collected by a motion capture system. Results illustrated that dancing with a partner has a significant effect on the angular kinematics of the lower extremity and pelvis. Dancers showed more restricted motion at the knee and hip in the sagittal and frontal planes when dancing with a partner. Additionally, differences were observed among the steps with most differences occurring between steps one and two and steps two and three in all three planes. These findings expand our knowledge of swing dancing biomechanics, possibly informing the design of future studies that will further expand our understanding of swing dancing.

KEY WORDS: Dance, Lindy hop, East Coast swing, motion analysis, angular kinematics, injury prevention

INTRODUCTION

Swing dancing dates back to the 1920's when the African American community discovered the Charleston and the Lindy hop while dancing to Jazz music in New York (12, 13). Swing dancing remains popular and continues to attract increasingly more individuals with its lively music and social atmosphere (13). Today, swing dancing is popular in the United States and around the world as swing dance contests and workshops are held internationally (2).

Considerable efforts have been dedicated to the motor control and biomechanical aspects of other types of dancing, such as tap dancing (10), ballet dancing (1, 9, 17), Irish dancing (15), flamenco dancing (4), and hip-hop dancing (6). However, research regarding the biomechanics of swing dancing movements is scarce, which is disproportional to swing dancing's continued popularity. For example, only three studies have been conducted on swing dancing. Selbach-

Allen and colleagues aimed to understand the pose a dancer selects when completing a partnered spin in the Lindy hop (11). The optimal pose was modeled based on the dancers' sizes, and estimates of the external forces, moment of inertia, and rotational acceleration of the couple. Results illustrated that being closer to the dancing partner is beneficial for a better spin; however, the results were not statistically significant. Another study analyzed the effect of different footwear conditions on the free moment during rotational movements in country swing dancing (8). A third study concluded that certain kinetic measurements of swing dancing, such as ground reaction force (GRF), loading rate, and joint power, did not differ when dancing with or without a partner, and that the second step of the triple step element generally produces the greatest forces (14). Yet, there is still a large gap in the literature regarding the biomechanics, in particular the kinematic aspect, of swing dancing.

One of the common dance elements in swing dancing is the triple step. It involves taking a short step to the side with one foot, bringing the second foot to meet the first, and then taking a larger third step to the side with the first foot again (Figure 1). The triple step in swing dancing is an upbeat dance element that embodies some bounce. After the first step to the side, dancers generally hop to replace the first foot with the second foot before moving into the third step, which can cause a brief flight phase between the first two steps. Given the characteristic features of the triple step element in swing dancing, it is important to analyze the movement patterns associated with each of the three steps of the triple step element.

Although swing dancing is typically executed with a partner; many dancers may practice moves individually. Therefore, it is important to understand how a partner may affect an individual dancer's biomechanics while dancing. For example, dancers need to be constantly mindful of the position of their own and their partner's body in space. The continuous mental load could distract dancers and alter their movements. A sound understanding of the potential impact of dancing with a partner versus without a partner on biomechanics could provide valuable information for improving dance performance. A previous study indicated that the lower limb joint moments could differ between dancing with and without a partner (14). Despite being meaningful, the kinetic information is not visible and may not provide a direct and comprehensive understanding of this swing dance element. On the other hand, a kinematic analysis of swing dancing could help individuals better understand the movement pattern of swing dancing. Additionally, the study that observed limited differences in GRF between dancing with and without a partner also found differences in joint moments between dancing with and without a partner. This indicates that there are likely differences in the joint kinematics that are contributing to those differences in joint moments during the two conditions. Further, dance is an artistic sport that is often judged on appearance in combination with footwork and rhythm and timing, so differences in kinematics can directly impact the outcome of a dance performance aesthetically as well as kinetically. Therefore, it is important to understand what the differences may be between dancing with versus without a partner so that adjustments can be made during the respective practices to train and maintain optimal kinematics for performance.

The main purpose of this study was to analyze the kinematics of the triple step element in experienced swing dancers. Because swing dancing involves a variety of movements, including stepping, hopping, and jumping, we were most interested in the movements of the lower extremity. In addition, swing dancing appears to involve significant pelvic motion. Thus, we chose to determine the peak ankle, knee and hip angles as well as the pelvis motion, in all three planes over each stance phase of the triple step element. The kinematic measurements were compared between dancing with versus without a partner, as well as across the three steps within each dance condition. This study had two hypotheses: 1) the lower extremity joint and pelvis angles would differ between dance conditions; and 2) the lower extremity joint and pelvis angles would be different among the three steps of the triple step element within each dance condition.

METHODS

Participants

As the first study of this nature, a power analysis was not conducted due to the lack of preliminary data. Eight healthy recreational swing dancers (30.9 ± 4.7 years) with 4.1 ± 3.1 years of dancing experience were enrolled (Table 1). Despite the small sample size, the information from this study could still provide insight into the anglular kinematics of swing dance. To be considered a recreational swing dancer, participants must have completed a minimum of 50 sessions of swing dancing within the preceding year, but never competed professionally. Participants had no known medical or musculoskeletal conditions, and had been free of injury for at least six months prior to participating in the study. Before participating in the study, all participants signed an informed consent document approved by Georgia State University's Institutional Review Board. This work was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (5).

Table 1. Demographic information in mean ± standard deviation.

Parameter	Value	Range
Gender	4F, 4M	
Age (years)	30.9 ± 4.7	24 – 40
Height (cm)	172.5 ± 7.5	161.5 – 184.0
Mass (kg)	73.6 ± 13.1	55.0 – 97.5
Dance experience (years)	4.1 ± 3.1	2 – 11

F = female; M = male.

Protocol

The experimental protocol can be found elsewhere (14). Briefly, participants first changed into form fitting clothing and standardized socks (Under Armour, MD, USA), then had anthropometric measurements taken including body height and mass, leg length, and knee and ankle width. Participants were given five minutes to complete a warm-up of their choice, and then 16 retroreflective markers were applied to anatomical landmarks following a lower extremity Vicon Plug-in-Gait marker set.

Participants performed a triple step to the right with and without a partner three times each (for a total of six trials) in a random order. Participants were instructed to complete the triple step in such a way that the first and the second steps landed on the first force plate, and the third step landed on the second force plate (Figure 1). The triple step is performed as three steps to the side, so the first and third steps were taken with the right leg, and the second step was taken with the left leg. Participants also performed a rock step back with the right foot immediately prior to the triple step to mimic the momentum involved in swing dancing. For the purpose of this study, we chose to focus on the stance phase of each limb.

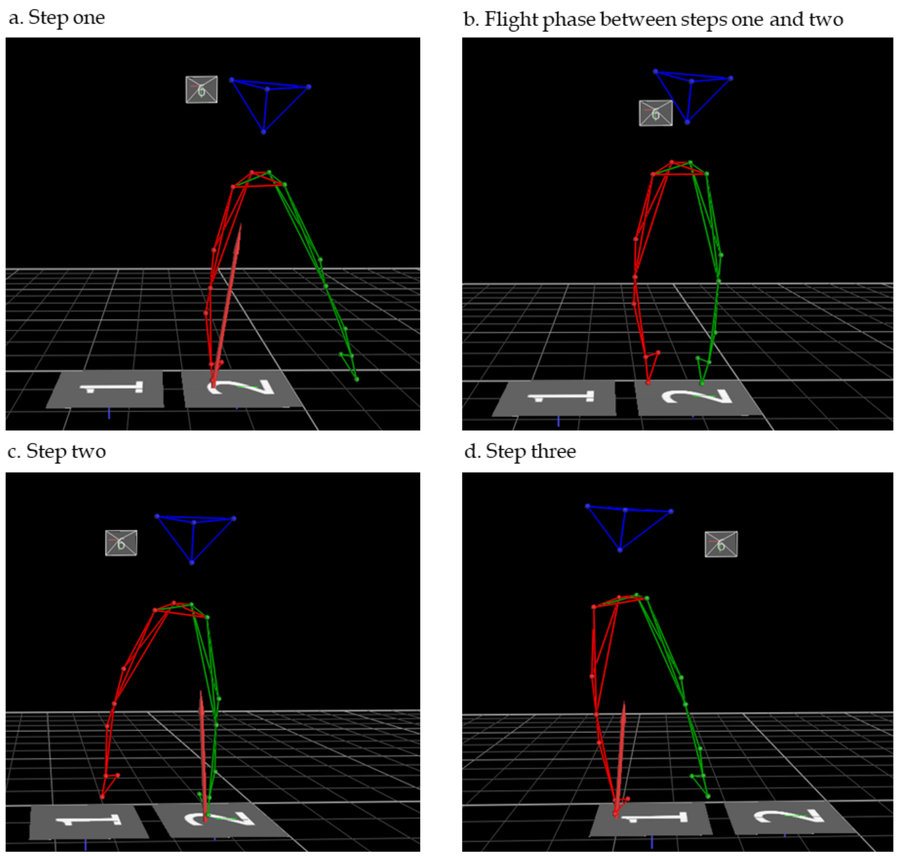

Figure 1. Illustrative body movement sequences of a triple step to the right and the illustration of the force plate set-up. When triple-stepping to the right, participants stepped the right foot onto the first force plate (**a**), brought the left foot to meet the right foot with a hop and a brief flight phase (**b**), the left foot then replaced the right one on the first force plate (**c**), then the right foot was stepped onto the second force plate where the participants were asked to end the movement and hold a static position for a few seconds (**d**). The squares on the floor show the respective force plate numbers and the upward arror on each force plate indicates the ground reaction force vector. The numbered square above the floor indicates the camera of the motion capture system.

Data was collected in pairs, and the motion capture procedure was arranged to gather dancers' kinetic and kinematic data individually and partnered. The three-dimensional lower extremity kinematics were collected via the markers by an 8-camera motion capture system (Vicon, UK) at 100Hz. Two force plates collected the GRF at 1000Hz, synchronized with the motion capture system.

Marker paths and GRF were low-pass filtered using fourth-order, zero-lag Butterworth filters with a cutoff frequency of 7 and 30Hz, respectively (7). Joint centers were calculated from the filtered marker paths and measured anthropometric parameters. The angles in the sagittal, frontal and transverse planes were determined for bilateral lower limb joints and the pelvis based on the joint center data using inverse kinematics. The joint coordinate systems were established based on the recommendations made by the International Society of Biomechanics (16).

All outcome measures were calculated over the determined landing phase. The timing of initial contact (IC) and toe-off (TO) of each of the three steps were determined by the vertical component of the GRF with a threshold force of 10N (3). The landing phase of each step was the duration from IC to TO. The following kinematic measurements were determined for the stance phase of each step: peak ankle, knee, and hip angles, and peak pelvis angular positions in both directions in all three planes of motion (sagittal plane: plantarflexion/dorsiflexion angles for ankle, flexion/extension angles for knee and hip, and anterior/posterior tilt angles for pelvis; frontal plane: eversion/inversion for ankle, abduction/adduction for knee and hip, and right/left upward obliquity for pelvis; transverse plane: internal/external rotation for ankle, knee and hip, and right/left forward rotation for pelvis). Average values over the three trials were calculated for each outcome variable for each of the three steps. A custom MATLAB (Mathworks, MA, USA) program was developed to conduct all calculations.

Statistical Analysis

Exploratory analyses were conducted to describe and summarize the data. Outcome measures were reported in mean ± standard deviation. Paired *t*-tests were used to compare the outcome measurements between dancing with and without a partner in order to test the first hypothesis. These comparisons were made for each of the three steps. Separate one-way analyses of variance (ANOVA) with repeated measures were used with the outcome measures as the dependent variables and the step number (first vs. second vs. third) as the within-subject factor to test the second hypothesis. When significant differences were seen, Bonferroni post-hoc tests were run. SPSS 27 (IBM, NY, USA) was used with a significance level of $\alpha = 0.05$.

RESULTS

Sagittal Plane Ankle Angles: Paired *t*-tests did show a significant between-condition difference in the peak ankle dorsiflexion angle during the first and third steps of the triple step (p=0.025 and 0.031, respectively). The ANOVA indicated that the step has an overall significant impact on the peak plantarflexion (p=0.043) and peak dorsiflexion (p=0.019) angles when dancing individually, and on the peak ankle dorsiflexion angle (p=0.018) during partnered dancing. Post-hoc analyses revealed that the peak ankle plantarflexion angle of the first step was significantly greater than the third step (p=0.049) during the individual condition, and the peak ankle dorsiflexion angle during the second step of the individual (p=0.019) and partnered (p=0.016) conditions were both greater compared to the third step of their respective condition (Table 2).

Sagittal Plane Knee Angles: Paired *t*-tests showed that a significant difference in the peak knee flexion angle between dancing conditions was observed during the first and third steps (p=0.009 and 0.013, respectively). The ANOVA indicated that the step has an overall significant impact on the peak knee extension angle (p=0.034) when dancing individually. Follow-up analyses revealed that the peak knee extension angle of the first step of the individual condition was significantly smaller than the third step (p=0.038) (Table 2).

Table 2. Comparisons of sagittal plane peak joint angles (in mean ± standard deviation) between dancing conditions (partnered vs. individual) and among steps (first vs. second vs. third). The former comparisons were conducted by paired *t*-tests and the latter ones were based on ANOVA. The *p*-values for comparisons showing significant differences are bolded.

Variable	Condition	Step 1	Step 2	Step 3	*p*-value (ANOVA)
Peak Ankle Plantarflexion	Individual	-5.697 ± 5.039	-1.159 ± 6.834	1.764 ± 5.096	**0.043**
	Partnered	-5.348 ± 3.086	-1.234 ± 6.348	-0.121 ± 5.919	0.182
	p-value (*t*-test)	0.552	0.445	0.112	
Peak Ankle Dorsiflexion	Individual	16.847 ± 5.750	22.641 ± 6.775	14.031 ± 4.171	**0.019**
	Partnered	14.684 ± 3.181	19.587 ± 7.209	11.011 ± 3.781	**0.018**
	p-value (*t*-test)	**0.025**	0.054	**0.031**	
Peak Knee Extension	Individual	25.756 ± 6.593	22.699 ± 9.989	14.342 ± 8.153	**0.034**
	Partnered	20.767 ± 7.159	21.453 ± 10.935	13.309 ± 6.003	0.155
	p-value (*t*-test)	0.057	0.451	0.156	
Peak Knee Flexion	Individual	40.383 ± 11.766	34.996 ± 11.348	32.529 ± 8.563	0.340
	Partnered	30.006 ± 11.136	34.935 ± 10.163	28.554 ± 10.340	0.508
	p-value (*t*-test)	**0.009**	0.704	**0.013**	
Peak Hip Extension	Individual	25.303 ± 11.877	21.143 ± 8.425	11.099 ± 10.689	**0.036**
	Partnered	23.587 ± 13.240	17.271 ± 6.698	11.157 ± 9.438	0.100
	p-value (*t*-test)	0.371	0.200	0.231	
Peak Hip Flexion	Individual	41.039 ± 10.560	28.557 ± 7.491	30.331 ± 11.342	**0.042**
	Partnered	35.553 ± 15.267	26.371 ± 5.180	27.808 ± 13.739	0.341
	p-value (*t*-test)	0.072	0.104	0.203	
Posterior Pelvic Tilt	Individual	2.562 ± 2.946	-2.064 ± 2.071	0.045 ± 3.018	**0.010**
	Partnered	1.697 ± 2.705	-1.513 ± 1.805	0.172 ± 2.640	0.070
	p-value (*t*-test)	0.113	0.779	0.662	
Anterior Pelvic Tilt	Individual	6.431 ± 3.270	3.308 ± 3.259	9.104 ± 3.522	**0.009**
	Partnered	4.275 ± 3.314	3.060 ± 2.867	7.590 ± 3.936	0.059
	p-value (*t*-test)	**0.012**	0.147	0.059	

Sagittal Plane Hip Angles: ANOVA results indicated that the step has an overall significant impact on the peak hip extension angle (p=0.036) when dancing individually. Post-hoc analyses revealed that the peak hip extension angle during the first individual step was significantly less than the third step (p=0.038) (Table 2).

Sagittal Plane Pelvis Angles: Paired t-tests exhibited a significant between-condition difference in the peak anterior pelvic tilt angle during the first step (p=0.012). The ANOVA indicated that the step has a significant main impact on the peak posterior (p=0.010) and peak anterior (p=0.009) pelvic tilt angles when dancing individually. Further analyses showed that the peak posterior pelvic tilt angle of the first step was greater compared to the second step (p=0.008) in the individual condition. During the same dancing condition, the peak anterior pelvic tilt angle of the second step was significantly smaller than the third step (p=0.007) (Table 2).

Frontal Plane Ankle Angles: The ANOVA indicated that the peak eversion and inversion angles were comparable between steps during partnered and individual dancing (p>0.05) (Table 3).

Frontal Plane Knee Angles: The paired t-tests revealed a significant difference between dancing conditions in the peak knee adduction angle during the third step (p=0.008). The ANOVA indicated that the step has an overall significant impact on the peak knee abduction and adduction under both dancing conditions (abduction: p<0.001 for both conditions; adduction: p=0.002 for individual and p=0.004 for partnered). Follow-up post-hoc analyses discovered that the peak knee abduction angle during the first and third steps were significantly greater than the second step during both dancing conditions (first step: p=0.003 for individual and p=0.002 for partnered; third step: p<0.001 for individual and p=0.001 for partnered). Additionally, the peak knee adduction angle during the second step was significantly greater compared to the first step in individual (p=0.004 for the first and p=0.005 for the third step) and partnered (p=0.004 for the first and 0.045 for the third step) conditions (Table 3).

Frontal Plane Hip Angles: A significant between-condition difference in the peak hip abduction angle during the second step was observed (p=0.021). The ANOVA indicated that the step has an overall significant impact on the peak hip abduction (p<0.001) and adduction (p=0.010) angles when dancing individually, and on the peak hip abduction (p=0.001) and adduction (p=0.039) angles when dancing with a partner. Follow-up analyses revealed that the hip joint exhibited a significantly smaller peak abduction angle during the first and third steps than the second step for both individual (p=0.001 for first and 0.003 for third step) and partnered (p=0.002 for first and 0.004 for third step) dance conditions. The peak hip adduction angle during the first step was significantly larger than the second step in both partnered (p=0.043) and individual (p=0.011) dancing (Table 3).

Table 3. Comparisons of Frontal plane peak joint angles (in mean ± standard deviation and Nm/kg) between dancing conditions (partnered vs. individual) and among steps (first vs. second vs. third). The former comparisons were conducted by paired *t*-tests and the latter ones were based on ANOVA. The *p*-values for comparisons showing significant differences are bolded.

Variable	Condition	Step 1	Step 2	Step 3	*p*-value (ANOVA)
Peak Ankle Eversion	Individual	-0.650 ± 2.206	-3.239 ± 6.459	-1.011 ± 2.607	0.428
	Partnered	-0.742 ± 1.906	-3.996 ± 6.745	-0.940 ± 2.452	0.306
	p-value (*t*-test)	0.988	0.520	0.474	
Peak Ankle Inversion	Individual	1.926 ± 3.306	1.012 ± 3.879	0.851 ± 2.783	0.789
	Partnered	2.063 ± 2.948	0.933 ± 4.199	1.021 ± 2.846	0.788
	p-value (*t*-test)	0.849	0.413	0.742	
Peak Knee Abduction	Individual	-16.127 ± 4.639	1.624 ± 14.841	-20.156 ± 3.249	**<0.001**
	Partnered	-18.465 ± 4.835	-1.828 ± 11.869	-20.774 ± 2.847	**<0.001**
	p-value (*t*-test)	0.156	0.611	0.487	
Peak Knee Adduction	Individual	-5.287 ± 3.445	9.451 ± 12.701	-4.955 ± 4.320	**0.002**
	Partnered	-5.975 ± 2.741	8.350 ± 11.520	-1.871 ± 3.458	**0.004**
	p-value (*t*-test)	0.189	0.075	**0.008**	
Peak Hip Abduction	Individual	2.817 ± 12.673	-17.508 ± 4.239	0.092 ± 8.490	**<0.001**
	Partnered	1.652 ± 9.313	-15.740 ± 4.776	0.039 ± 8.259	**0.001**
	p-value (*t*-test)	0.649	**0.021**	0.230	
Peak Hip Adduction	Individual	11.276 ± 10.304	-2.850 ± 6.718	7.709 ± 8.494	**0.010**
	Partnered	10.209 ± 8.592	-1.198 ± 6.320	7.054 ± 8.537	**0.039**
	p-value (*t*-test)	0.828	0.212	0.075	
Left Pelvic Obliquity	Individual	8.261 ± 6.086	-17.684 ± 4.628	5.606 ± 6.347	**<0.001**
	Partnered	12.871 ± 4.803	-14.842 ± 3.265	11.795 ± 4.289	**<0.001**
	p-value (*t*-test)	0.303	**0.007**	0.084	
Right Pelvic Obliquity	Individual	10.744 ± 5.850	-15.148 ± 4.685	10.486 ± 5.259	**<0.001**
	Partnered	15.144 ± 5.333	-11.081 ± 4.223	16.090 ± 3.520	**<0.001**
	p-value (*t*-test)	0.344	**0.029**	0.057	

Frontal Plane Pelvis Angles: Paired *t*-tests showed a significant condition-associated difference in the minimum and maximum pelvic obliquity angles during the second step (p=0.007 and p=0.029, respectively). The ANOVA indicated that the step has an overall significant impact on the minimum and maximum pelvic obliquity angles for both dancing conditions (p<0.001 for all). The minimum and maximum pelvic angles were significantly different between both the first and second step and between the second and third step for both dancing conditions (p<0.001 for all). Further analyses of the minimum and maximum pelvic obliquity angles illustrated that right side upward pelvic obliquity was evident throughout all three steps. Additionally, the first and third steps resulted in greater right upward pelvic obliquity compared to the second step during both dancing conditions (Table 3).

Transverse Plane Ankle Angles: There were no significant condition- or step-related differences observed in the peak ankle external or internal rotation angles (p>0.05 for all comparisons, Table 4).

Transverse Plane Knee Angles: No significant differences in the peak knee internal or external rotation angles were observed between partnered and individual dancing for any of the three steps (p>0.05 for all). The ANOVA indicated that the step has a significant impact on the peak knee external rotation angle during the individual dance condition (p=0.046). However, there were no significant differences following post-hoc analyses (Table 4).

Transverse Plane Hip Angles: There were no significant condition- or step-related differences observed in the peak hip internal rotation angle (p>0.05 for all comparisons). The ANOVA indicated that the step has a significant impact on the peak hip external rotation angle during the individual dance condition (p=0.041). Follow-up post-hoc tests, however, did not detect any significant between-step differences (p>0.05) (Table 4).

Transverse Plane Pelvis Angles: The ANOVA indicated that the peak pelvic external and internal rotation angles were significantly different among steps for both dancing conditions (p<0.001 for both conditions, Table 4). Post-hoc analyses illustrated that both dancing conditions resulted in the right side of the pelvis being rotated forward during all three steps. Further, the second step resulted in significantly less right-side forward rotation than the first and third steps in both dancing conditions.

DISCUSSION

This study aimed to analyze angular kinematics of the triple step in recreational swing dancers and to determine if and how the kinematic measurements differ between dancing with versus without a partner, and across the steps within the element. Results revealed that significant between-condition differences occurred at the knee joint and pelvis in the sagittal plane, at the knee, hip, and pelvis in the frontal plane, and at the pelvis in the transverse plane. Among steps, the majority of the differences seen in the sagittal plane happened while dancing individually. In the frontal plane, there were no differences seen at the ankle for either dancing condition. In the transverse plane, almost all the differences among the three steps were associated with the pelvis.

Table 4. Comparisons of Transverse plane peak joint angles (in mean ± standard deviation and Nm/kg) between dancing conditions (partnered vs. individual) and among steps (first vs. second vs. third). The former comparisons were conducted by paired *t*-tests and the latter ones were based on ANOVA. The *p*-values for comparisons showing significant differences are bolded.

Variable	Condition	Step 1	Step 2	Step 3	*p*-value (ANOVA)
Peak Ankle External Rotation	Individual	-12.067 ± 17.995	-8.609 ± 21.968	-5.098 ± 17.914	0.775
	Partnered	-10.533 ± 15.079	-5.814 ± 22.595	-4.470 ± 18.307	0.822
	p-value (*t*-test)	0.994	0.766	0.351	
Peak Ankle Internal Rotation	Individual	5.280 ± 16.939	11.537 ± 26.837	7.052 ± 20.026	0.839
	Partnered	5.843 ± 14.322	15.869 ± 27.694	7.620 ± 18.402	0.639
	p-value (*t*-test)	0.769	0.337	0.370	
Peak Knee External Rotation	Individual	1.800 ± 19.605	-19.072 ± 10.073	-1.263 ± 19.058	**0.046**
	Partnered	-1.938 ± 15.647	-19.245 ± 11.506	-3.985 ± 17.753	0.093
	p-value (*t*-test)	0.371	0.403	0.640	
Peak Knee Internal Rotation	Individual	7.942 ± 19.689	-4.574 ± 9.265	5.408 ± 18.563	0.298
	Partnered	2.877 ± 15.974	-3.006 ± 9.158	2.825 ± 18.591	0.709
	p-value (*t*-test)	0.205	0.218	0.495	
Peak Hip External Rotation	Individual	-15.041 ± 8.528	-1.639 ± 18.376	-17.860 ± 8.535	**0.041**
	Partnered	-13.979 ± 7.965	-4.535 ± 16.865	-15.998 ± 7.523	0.172
	p-value (*t*-test)	0.741	0.776	0.768	
Peak Hip Internal Rotation	Individual	-5.041 ± 9.786	7.647 ± 18.819	-8.194 ± 7.307	0.054
	Partnered	-5.375 ± 9.552	4.745 ± 16.960	-9.260 ± 8.119	0.113
	p-value (*t*-test)	0.138	0.753	0.204	
Left Pelvic Rotation	Individual	71.504 ± 8.723	-84.092 ± 5.419	79.382 ± 6.045	**<0.001**
	Partnered	69.557 ± 14.671	-86.648 ± 5.909	77.265 ± 11.076	**<0.001**
	p-value (*t*-test)	0.869	0.273	0.730	
Right Pelvic Rotation	Individual	82.133 ± 6.109	-77.408 ± 6.117	89.782 ± 4.013	**<0.001**
	Partnered	77.079 ± 15.105	-71.834 ± 15.343	90.285 ± 8.059	**<0.001**
	p-value (*t*-test)	0.532	0.494	0.818	

The results partially supported our first hypothesis, which states that the joint angles in each of the three planes would be different when compared between dancing with versus without a partner. In the sagittal plane, there were differences in the ankle and knee angles, and pelvis positions. At all joints, dancers exhibited greater degrees of flexion when they were performing the triple step individually, which could indicate that dancers feel the need to restrict their movements more when dancing with a partner. These findings could also be tied to the need to be aware of their partners' position and movements in order to avoid interfering with their movement. The connection in which two dancers establish between them could also affect the kinematics of the motions. For example, a more open handhold would allow for greater flexion to occur, whereas a more closed position could lend itself to more restricted movements, primarily in the sagittal plane. However, swing dancing typically adopts a more open connection which would alleviate this factor. In the frontal plane, differences were seen at the knee, hip, and pelvis, which could again indicate a restriction of movement based on their partners' position in space. In the transverse plane, however, there were no differences observed between dancing with and without a partner. This indicates that having a partner does not alter the amount of rotational movement that occurs in the lower extremity during the stance phase of the triple step movement.

Our results could be related to differences in joint moments reported in a previous study that examined the kinetic aspect of swing dance (14). It was indicated that the lower extremity joint moments were different between dancing conditions. Specifically, there were differences seen in the knee extension moments, hip abduction moments, and the ankle internal and external rotation, as well as knee external rotation. Partnered dancing poses an extra challenge to the dancers in comparison with individual dancing, as dancers must ensure that they are exchanging the correct signals with their partner and coordinating their movements accordingly. This extra challenge may alter movements between dancing conditions. To meet the changes in body kinematics from individual to partnered dancing or vice versa, the joint moments, which are the driving force to produce the kinematics, need to be altered accordingly. Therefore, the findings in terms of the kinematic measurements not only confirm the results from a previous study concerning the kinetic measurements of swing dancing (14), but augment our understanding of the biomechanics of swing dance. The differences in the leg angular measurements and in the joint moments between dancing conditions suggest that dancing individually may not be an adequate substitution for partnered swing dancing.

The results also partly supported our second hypothesis that there would be differences among each of the three steps of the triple step movement. In the sagittal plane, very few differences were observed among the three steps when dancing with a partner, which reflects the change in the angular measurements from dancing individually to dancing with a partner. Additionally, the differences observed occurred between steps one and two, two and three, and between steps one and three. The observed differences between steps one and two and between two and three could be a result of the above-mentioned form differences, including taking steps one and three with the right leg and taking step two with the left leg, in addition to the flight phase prior to the second step that does not occur before steps one and three. In addition, the observed differences between steps one and three, despite these steps being taken with the same leg, could be because there is continued movement and momentum required after steps one and two in contrast to stopping and stabilizing after the third or final step.

In the frontal plane, there were no differences among the three steps at the ankle, but numerous differences were seen at the knee and hip in both individual and partnered conditions. Again, the majority of the differences seen were between steps one and two, and between steps two and three. This could again be due to steps one and three being taken with the right leg and step two being taken with the left leg. Additionally, the results observed could also be because steps one and three are stepped into, while there is a slight hop from step one to step two. Therefore, the landing of the second step frequently occurs after a brief flight phase.

At the pelvis, there were significant differences among the three steps in all three planes of motion. Most of the observed differences in the transverse plane were between the first and second steps and between the second and third steps. This is logical as the triple step to the right, which is the stepping movement of interest in the present study, involves a step with the right side, then the left side, followed by a third step with the right side. The differences in pelvic rotation seen in this study reflect the difference between stepping with the right side and stepping with the left side. There were few other differences among the three steps in the transverse plane, indicating that the rotation at each of the lower extremity joints is very similar across the stance phase of all three steps.

Our study does have a few limitations. First, the relatively small sample size (n = 8) and the targeted dance level (recreational) and movement (triple step) of this study could limit the generalizability of our findings. However, as the first of its kind, our study would still shed light on our understanding of the swing dancers' joint kinematics and inform the design of future studies. Second, the possible kinematic difference between genders was not considered due to the small sample size. Men and women have some anatomical differences. Thus, it is possible that between-gender kinematic differences could exist. Lastly, the electromyography signals of the leg muscles were not collected. This information could provide insight into the sequence and magnitude of muscle activity and should be considered in the future. These issues necessitate future studies with larger sample sizes and quality designs. Future research should be conducted on additional dance steps in order to gain a broader understanding of the biomechanics of swing dancing.

Along with the previous study concerning the kinetics of triple steps among recreational swing dancers (14), this study may aid dance instructors in designing training plans for swing dancers. The knowledge gained in this study may also help dancers improve swing dance performance. For example, the difference between dancing with and without a partner indicates that dancing individually may not be a suitable substitute for dancing with a partner in terms of performance. Additionally, information from this study combined with information from our prior study (14) may help dancers and trainers to avoid dance related injuries. Lastly, this study may be used to assist in the design of future studies. This study analyzed only one swing dance element, which by no means can represent the countless dance elements incorporated in swing dancing. Therefore, future research should be executed to better understand the technique and forces involved in additional elements of swing dancing.

This study, as the first attempt to examine the kinematics of swing dance movements, provides key information regarding the lower limb angular kinematics of the triple step movement in swing dance. Results suggested that the angular kinematics of the lower extremity and pelvis are affected by the step and dancing condition for the triple-step movement. This is important knowledge that should be noted in the future design of swing dance training programs and performance assessments.

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