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Trunk Coordination in Dancers and Non-Dancers

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ABSTRACT

Variability, or how a task changes across trials, may reveal differences between athletes of differing skill levels. The purpose of this study was to examine trunk and lower extremity (LE) single joint kinematic variability and inter-segmental coordination variability in dancers and non-dancers during bipedal vertical dance jumps (sautés). Twenty healthy females, ten with no formal dance training and ten professional dancers, performed 20 consecutive sautés. Single joint kinematic variability was assessed using mean standard deviation of angular displacement, and inter-segmental coordination variability was assessed using angular deviation of the coupling angle between segments. Within the context of the standard error of measure, there was no difference in single joint kinematic variability between dancers and non-dancers. Inter-segmental coordination variability in the trunk was higher than variability in LE couplings for both groups. Dancers had lower inter-segmental coordination variability than non-dancers for LE sagittal, frontal and transverse plane couplings and sagittal plane trunk couplings. Trunk adjustments may be important for successful performance, but lower inter-segmental coordination variability in expert dancers indicates a higher level of control. Trunk coordination and postural control may be important factors to investigate in skilled athletes.

Key Words: Dance, Variability, Vector Coding, Jumping

Word Count: 3338

Introduction

Persons with different levels of skill are capable of successfully performing athletic movements. The appearance of difficult or complex athletic movements is often noticeably different in athletes of varying skill levels, but differences between novice and expert performers in relatively simple movements may be subtle and less easily apparent. Examination of a movement that can be successfully performed by both novice and expert performers provides insight into differing movement strategies due to level of training.

Coordinated, functional movement requires the control of a large number of muscles and joints within the human body.[1,2] Coordination is a complex motor control problem because the nervous system is faced with the demand of controlling multiple interdependent elements simultaneously. The acquisition of a coordinated motor skill involves trying to find ways of controlling the degrees of freedom to allow for effective movement.[2] Control and coordination cannot be studied in terms of individual joints, but should instead include multiple joints and investigate the interaction between body segments.[2,3] Examination of coordination between different body segments may allow for the identification of differences between novice and expert performers that would not otherwise be seen.

Variability, or how a task changes across repeated trials, is an important factor in skill development, as it allows an individual to explore a task and find an efficient pattern for task completion.[4] Single joint kinematic variability, expressed as the standard deviation or coefficient of variation of displacement across multiple trials, is often used to assess the consistency of movement patterns.[5,6] Single-joint kinematics relate more readily to features of movement that are observed clinically or in a coaching environment, but the relative movement between joints may also be important in the development of highly skilled movements. Inter-segmental coordination variability looks at the variability of movement between joints, and both single joint kinematic and inter-segmental coordination variability have been related to athletic skill level.[7-9]

Variability itself is not necessarily good or bad, but is reflective of the flexibility and stability of a system.[10] In the process of mastering a particular task, single joint kinematic and inter-segmental coordination variability may be gradually decreasing or increasing, depending on an athlete's level of skill.[7,8,11] Even after skill acquisition is complete, variability exists in movements with similar outcomes. Single joint kinematics may be similar while single joint kinematic and inter-segmental coordination variability differ between athletes with varying levels of skill.[5,7,8] In addition, within-task variability emerges as a result of accruing expertise in performing a task. While overall variability decreases with years of practice, distinct peaks in variability preceding critical events during a task (such as ground contact) may emerge.[12] Several studies have suggested that after skill acquisition, variability continues to play a functional role, as it may allow for adaptations to the environment, reductions in injury risk, or the facilitation of changes in coordination patterns.[3,8,13,14] However, too much variability may interfere with efficient performance of a task. There is likely an optimal level of variability, achieved by expert performers, that allows for the most successful performance.[14]

Dancers are skilled athletes who perform within a unique set of movement constraints. Dance emphasizes the artistic appeal of movements, so it is important that each movement fulfills certain aesthetic requirements. Thus, it seems that excessive variability would be undesirable for a dancer. Studies examining postural control during balance tasks have found less variable coordination patterns in skilled dancers compared to less-skilled dancers or non-dancers.[5,15] Different body segments may also demonstrate distinct variability patterns from each other within a task, depending on the task or an individual's ability to control individual body segments.[5] The most noteworthy differences between novice and expert dancers during an arabesque movement were seen in the pelvis, while movement was more consistent among dancers of different skill levels in the lower extremities.[5] Experienced dancers demonstrated more pelvic transverse plane rotation and frontal plane translation than less-skilled dancers, and expert dancers also exhibited less variable pelvic translation during the arabesque.[5] In performing jumping maneuvers, the interaction with the ground may affect inter-segmental coordination variability. A study of expert dancers found coordination patterns and variability trends specific to different phases in jumping, with trunk coordination variability increasing just prior to landing and during the transition between landing and propulsion for the next jump.[12] Biomechanical analyses of coordination patterns and movement variability have not been studied in dancers of varying skill levels during jumping movements.

The purpose of this study was to examine trunk and lower extremity single joint kinematics and inter-segmental coordination variability in dancers and non-dancers during rate-controlled bipedal vertical dance jumps (sautés). Controlling the rate of the sauté movement will impose certain kinematics inherent to the task itself, resulting in a certain level of consistency across trials. We hypothesized that the inter-segmental coordination variability, but not the single joint kinematics, would differ between dancers and non-dancers performing repeated sautés. In particular, we expected dancers to demonstrate lower trunk and lower extremity inter-segmental coordination variability than non-dancers. We also hypothesized that inter-segmental coordination variability of the trunk would peak just prior to landing, in dancers only.

Methods

Participants

Twenty healthy females between the ages of 18 and 35 were recruited for this study. Ten of these were females who had no prior formal dance training, while the other ten females were professional dancers with over ten years of formal dance training. Inclusion in the dance group also required employment as a dancer or teacher within the past year and continued training at a high level. Participants were excluded from the study if they were suffering from any current injury that would impair their ability to jump. Ethical approval for the study was received from the Institutional Review Board of the University of Southern California, and all participants provided written informed consent.

Instrumentation

An 11 camera three-dimensional motion analysis system (Qualisys, Sweden) was used to collect kinematic data at 100 Hz, and ground reaction force data was collected at 1500 Hz (AMTI, Watertown, MA). Triads of rigid reflective tracking markers were securely placed on the subject's thoracic spine (T3), lumbar spine (L1), thighs, lower legs, and heels. Additional tracking markers were placed on each anterior superior iliac spine, iliac crest, and acromioclavicular joint, as well as on the C_7 and L_5 spinous processes. A standing calibration trial was used to derive the local coordinate systems and segment endpoints.

Procedures

Participants performed 20 consecutive sautés (bipedal dance jumps) at a controlled rate of 95 beats per minute. This rate was chosen to reflect a speed similar to that which may be used in a typical dance class. The arms were held over the head in ballet 5^{th} position and the task was performed with each foot on a force plate (Figure 1). Practice trials were performed until participants were comfortable with the procedures and wearing the markers. A trained dance teacher was present to ensure proper technique and to instruct non-dancers in proper performance of the skill. Trials were deemed acceptable if the participant was able to perform at least 20 jumps at the controlled rate while maintaining the trunk in an erect posture, keeping the arms overhead, and staying on the force plates throughout the trial.

Data Processing

Markers were manually identified using Qualisys software, then kinematic data were imported into Visual3D™ (C-Motion, Inc., MD, USA). Marker data were low-pass filtered using a bi-directional fourth-order Butterworth filter with a frequency cutoff at 12 Hz. A three-segment trunk model was used, consisting of a pelvic segment referenced to the global coordinate system, a lumbar segment referenced to the pelvic coordinate system, and a thoracic segment referenced to the lumbar coordinate system.[12] In the lower extremity, thigh, shank, and foot segments were modeled with reference to the proximal segment. The kinematics of the model were calculated by determining the transformation from each segment's triad of reflective markers to the position and orientation of each segment determined from the standing calibration trial. The duration of each jump was normalized to 100 intervals in the time domain using linear interpolation.

Data Analysis

For each participant, the sauté jump was subdivided into five phases (Figure 2): initial stance (defined from the lowest point of the L5 marker to the instant when the feet leave the ground), early flight (rising portion of flight, defined from toe-off until the L5 marker reached its highest point), lowering flight (defined from the highest point of the L5 marker until the instant when feet return to the ground), and final stance phase (defined from the instant of touchdown until the lowest point of the L5 marker). The lowering flight phase was further divided into two halves, referred to as late flight (first half) and pre-landing (second half) in order to identify changes in variability just prior to landing. The cut-off for toe-off and touchdown identification was defined as a vertical ground reaction force of less than 20 N and greater than 20 N, respectively.

Sagittal, frontal, and transverse plane thoracic, lumbar, hip, knee, and ankle angular displacement was calculated for the middle 10 consecutive jumps (removing the first 5 and last 5 jumps) for each participant, to eliminate the potential effects of the initiation and termination of the task. Single joint kinematic variability was assessed using the mean standard deviation of the angular displacement for individual joints or trunk segments, for each participant both across the entire jump cycle and within the different phases of the jump.

There are several methods appropriate for quantifying inter-segmental coordination, such as continuous relative phase and vector coding.[12] For the purposes of this analysis, vector coding was used as this technique does not require amplitude normalization procedures, so the true magnitude of movement at each joint is preserved.[12] As the purpose of this study was to compare single joint kinematic variability and inter-segmental coordination variability, a method closely related to the original kinematic variables was preferred. The vector coding method was used to quantify inter-segmental coordination variability in the spatial domain (Figure 3).[3,16] Using MATLAB software (MathWorks, MA, USA), an angle-angle plot of joint motion was created for ankle-knee, knee-hip, and thoracic-lumbar couplings. For each time interval, a coupling angle between 0 and 360° was determined as the angle of a vector connecting two consecutive data points on the angle-angle plots compared to the right horizontal.[16] The mean coupling angle across the 10 trials was calculated for each participant using circular statistics, and the angular deviation of the coupling angle (the circular equivalent of standard deviation) was used to assess inter-segmental coordination variability across the entire jump cycle and within each phase of the jump.

Prior to data collection, test-retest reliability of kinematic measures and vector coding measures were obtained by testing 5 subjects on two visits at least one week apart. The consistency of peak kinematic and mean coupling angle values were quantified using intraclass correlation coefficients (ICC), and the ICC was used to calculate the standard error of the measurement.

Statistical Analysis

Statistical analyses were performed using SPSS statistical software (Chicago, IL), with significance levels at $P \leq .05$. Demographic characteristics of participants were compared using independent t-tests. Overall single joint kinematic and inter-segmental coordination variability trends between groups for the trunk and the lower extremities were examined using independent t-tests with Bonferroni corrections, with an adjusted significance level of $P \leq .01$ for kinematics (five comparisons) and $P \leq .02$ for coordination (three comparisons). Inter-segmental coordination variability in different body regions was compared using a one-way ANOVA. Factorial ANOVAs were used to compare inter-segmental coordination variability in the two groups across the five phases of the jump. For all ANOVAs, significant main effects are reported unless there were interactions, which required individual analysis.

Results

No significant group differences in subject demographics were observed beyond the intentional difference in dance training, with the dance group having an average of approximately 21 (20.8 ± 5.3) years of training (Table 1). Kinematic profiles were generally similar in shape between the two groups (Figure 4), indicating that both groups were successful in performing the bipedal, rate-controlled jumping task.

Examination of single joint kinematic variability in the sagittal plane revealed a statistically significant difference between groups, with lower single joint kinematic variability for dancers than for non-dancers, for the lower extremity joints (ankle $P<.001$, knee $P<.001$, hip $p<.001$) but not for the trunk (lumbar $P=.448$, thoracic $P=.048$) (Figure 5). However, the difference in lower extremity variability between groups (ankle=0.85°, knee=0.89°, hip=0.95°) was smaller than the standard error of measure for any of the three lower extremity joints (SEM ankle=0.92°, knee=2.12°, hip=3.34°). Therefore, there is not likely a meaningful difference in single joint kinematic variability between the two groups for any of the joints studied. In the frontal and transverse planes, there were no statistically significant differences in single joint kinematic variability between groups for any of the lower extremity joints or trunk segments (Figure 5). Total excursion of the trunk in the frontal and transverse planes was smaller than the standard error of measurement for the motion capture system (Figure 4), so inter-segmental coordination variability of the trunk was only assessed in the sagittal plane (Figure 5).

When looking at the coordination between segments, there were significant differences in inter-segmental coordination variability in the sagittal plane between dancers and non-dancers for both lower extremity (ankle-knee=5.66° difference between groups, $P<.001$, knee-hip=4.59° difference, $P<.001$) and trunk (thoracic-lumbar=6.18° difference, $P=.009$) couplings (Figure 5). In the frontal and transverse planes, there were also significant differences in inter-segmental coordination variability between dancers and non-dancers for both the ankle-knee coupling (frontal=6.78° difference, $P<.001$, transverse=5.7° difference, $P=.003$) and the knee-hip coupling (frontal=12.28° difference, P<.001, transverse=8.6° difference, P<.001) (Figure 5). In all cases, dancers demonstrated lower variability than non-dancers (Figure 5). The differences between groups were higher than the calculated standard error of measure (SEM thoracic lumbar coupling=0.58°, hip-knee coupling=1.46°, ankle-knee coupling=1.67°). For both groups, sagittal plane inter-segmental coordination variability in the trunk was higher than variability in either of the lower extremity couplings (P<.001).

In an effort to quantify potential changes in trunk inter-segmental coordination variability just prior to jump landing, coordination variability across the jump phase was assessed for sagittal plane couplings only. For the lower extremity sagittal plane couplings (ankle-knee and knee-hip), there was a main effect of jump phase (P<.001) on inter-segmental coordination variability, but no interaction between group and jump phase (Figure 6). Variability was lower during initial stance, pre-landing, and final stance and higher during early flight and late flight; this relationship held true for both dancers and non-dancers. There was no main effect of jump phase (P=.07) on inter-segmental coordination variability for the trunk coupling in the sagittal plane and no interaction between group and jump phase (P=.39) (Figure 6). However, during the pre-landing phase, the mean variability for dancers (42.4°) was higher than for non-dancers (39.4°). This was the only time where the variability of trained dancers exceeded the variability of non-dancers, but the difference was not statistically significant.

Discussion

Trained dancers demonstrated similar single joint kinematic variability but lower inter-segmental coordination variability compared to non-dancers during a simple jumping task. While many dance movements are complex tasks that require years of training to master, the sauté jump chosen for this examination is simple enough that non-dancers were able to successfully complete the task. Non-dancers performed the sauté jumps with kinematic patterns very similar to those of trained dancers. The repetition of a simple jumping task allowed for examination of variability across multiple trials. Overall, analysis of single joint kinematic variability did not reveal meaningful differences between groups.

Inter-segmental coordination variability was lower in dancers than in non-dancers, in lower extremity sagittal, frontal, and transverse plane couplings and in sagittal plane trunk couplings. These results are consistent with findings in previous studies which have shown that less experienced individuals typically demonstrate greater variability in a particular task as they explore options for completing the task.[4,7] As learning progresses, individuals establish successful movement patterns and the magnitude of variability decreases, eventually approaching similarity with variability patterns seen in expert performers. More experienced individuals complete tasks with lower variability, but some degree of variability remains present to allow for adjustments in balance, timing, and any other applicable factors.[8] An optimal level of variability may exist, which allows for a balance between consistency and the ability to adjust a movement as needed during performance.

For both dancers and non-dancers, sagittal plane inter-segmental coordination variability was lower in the lower extremity than in the trunk. The movements of the lower extremity are what defines the goal of the task, and much of this movement is driven by the interaction between the feet and the ground; variability in the lower extremity couplings was especially low during the stance phases where the feet were in contact with the ground. It seems there is little room for changes and adjustments in the lower extremity during the sauté task. The trunk segments have more freedom to move and adjust throughout completion of the jumping task, which is likely why greater variability is seen in the trunk. Adjustments in the trunk also may affect overall body alignment, and allow for more successful task performance. However, experienced dancers still demonstrated overall lower trunk inter-segmental coordination variability than non-dancers, possibly indicating a higher level of control. Previous research in dancers performing a leg extension demonstrated that expert dancers differed from novice dancers in terms of postural pelvic control, suggesting that control of the pelvis requires extended practice, while control of the lower extremities is easier for novice dancers to achieve.[5] Examination of trunk coordination and postural control may be important in determining movement patterns associated with high levels of skill.

A previous study of only high-level dancers found that mean inter-segmental coordination variability in the trunk peaked just prior to landing; it was suggested that this peak occurred as the dancers corrected alignment in preparation for the impact with the ground.[12] In the current study, we have observed the same heightened inter-segmental coordination variability in the trunk, likely necessary as a feed-forward phenomenon. Since the current study compared two groups, an attempt was made to quantify this peak that was previously observed qualitatively in trained dancers, but a statistically significant difference from non-dancers was not found. While not statistically significant, during the pre-landing phase just prior to contact with the ground, sagittal plane inter-segmental coordination variability in the trunk was higher for dancers than for non-dancers. This was the only phase for either single joint kinematic or inter-segmental coordination variability where dancers demonstrated higher variability than non-dancers, suggesting the vital role of variability in trunk coordination required for this task. The lack of statistical significance may be due to a certain demand for optimal variability (not too much or too little) that must be met, regardless of training, for a successful landing and consecutive takeoff. Other factors, such as limited sample size or the analytical methods used to define jump phases in an effort to identify the time that would include preparation for landing should also be considered as contributing to the lack of statistical difference between groups. The jump cycle was broken into five phases in an effort to isolate the peak in variability seen just prior to ground contact in previous research,[12] but dividing the flight phase temporally by percentage of jump cycle may not be the optimal method for quantifying the presence of this peak.

Results from this study demonstrate that examination of coordination between joints allows for a more thorough interpretation of skilled athletic movements than single joint kinematic analysis alone. In a simple sauté jumping task, highly trained dancers and non-dancers demonstrated similar single joint kinematic variability but differences in the variability of coordination between joints. The lower inter-segmental coordination variability seen in trained dancers exhibits itself in all three cardinal planes for the lower extremities. Overall, experienced dancers performed repetitions of the jump with decreased inter-segmental coordination variability compared to non-dancers, suggesting that practice has allowed them to establish a consistent approach for successful completion of the task.

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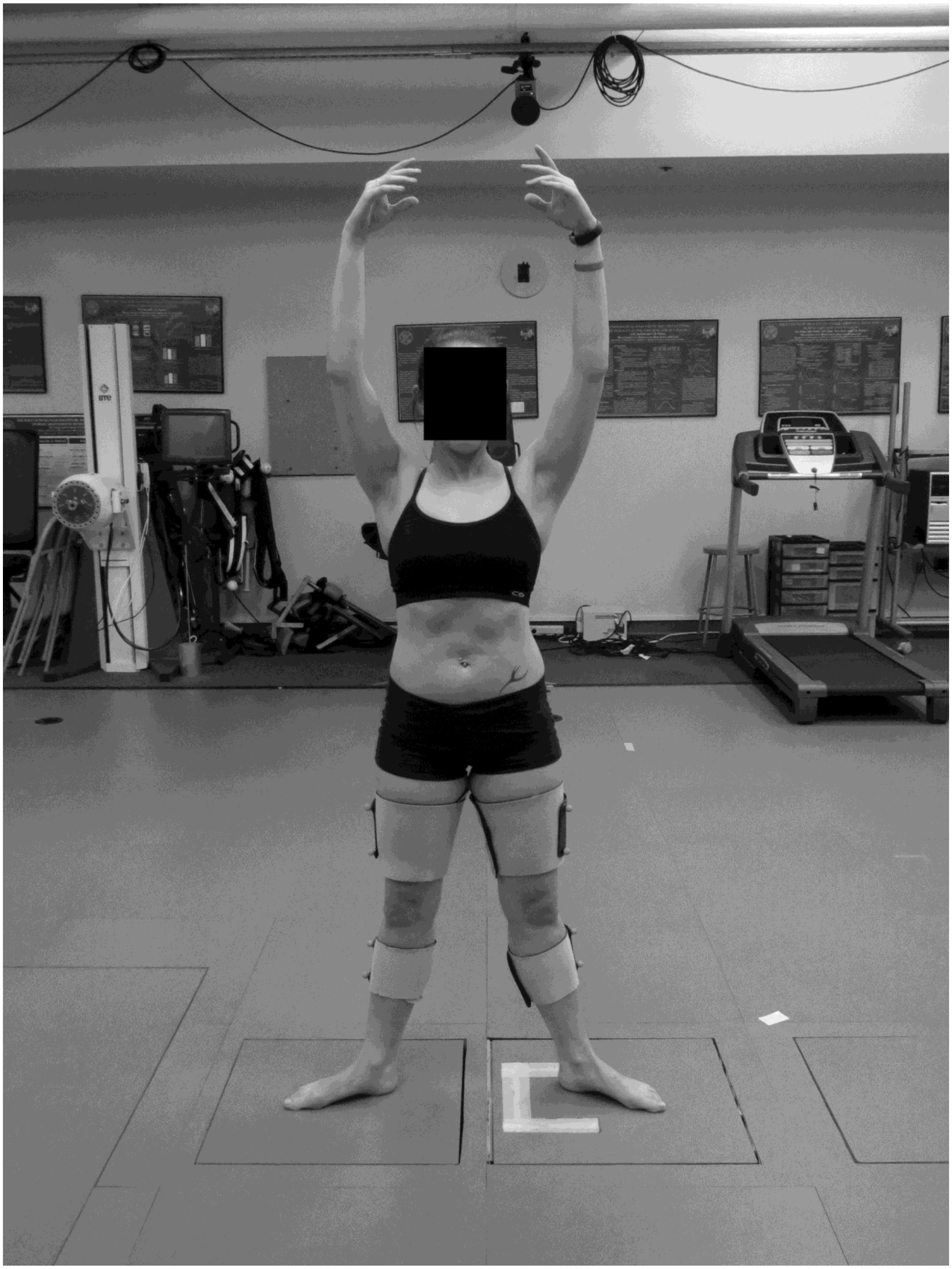

Figure 1. Dancer's body position during sauté jumps.

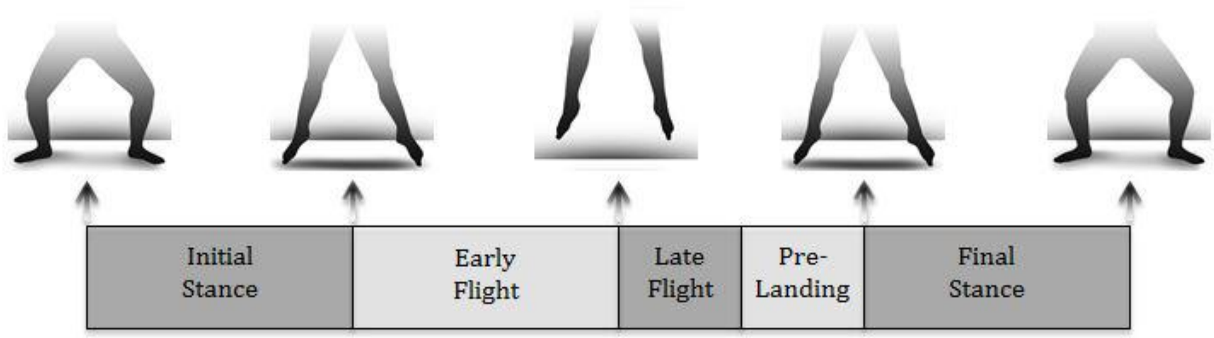

Figure 2. Definition of phases of the sauté jump: Initial stance phase defined from the lowest point of the L5 marker to the moment when the feet leave the ground; Early flight phase, the rising portion of flight defined from the moment when the feet leave the ground until the L5 marker reached its highest point; Lowering flight phase, defined from the highest point of the L5 marker until the moment when feet return to the ground- this phase was further broken into halves, referred to as late flight (first half) and pre-landing (second half); Final stance phase, defined from the moment when the feet return to the ground until the lowest point of the L5 marker.

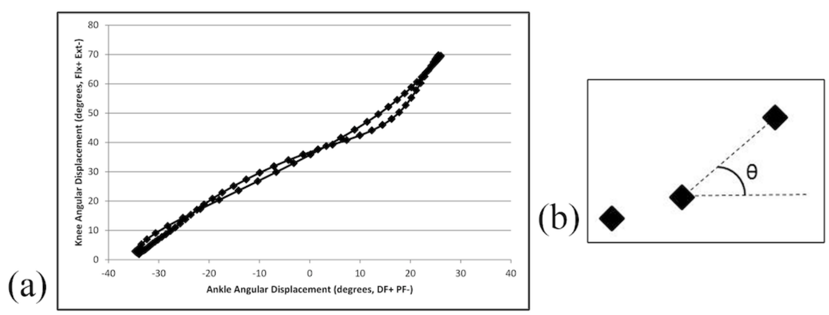

Figure 3. Illustration of the vector coding method. (a) Sample angle-angle plot of ankle and knee displacement for one representative dance subject; (b) Sample calculation of coupling angle θ based on the angle between a vector connecting two consecutive points on the angle-angle plot and the right horizontal.

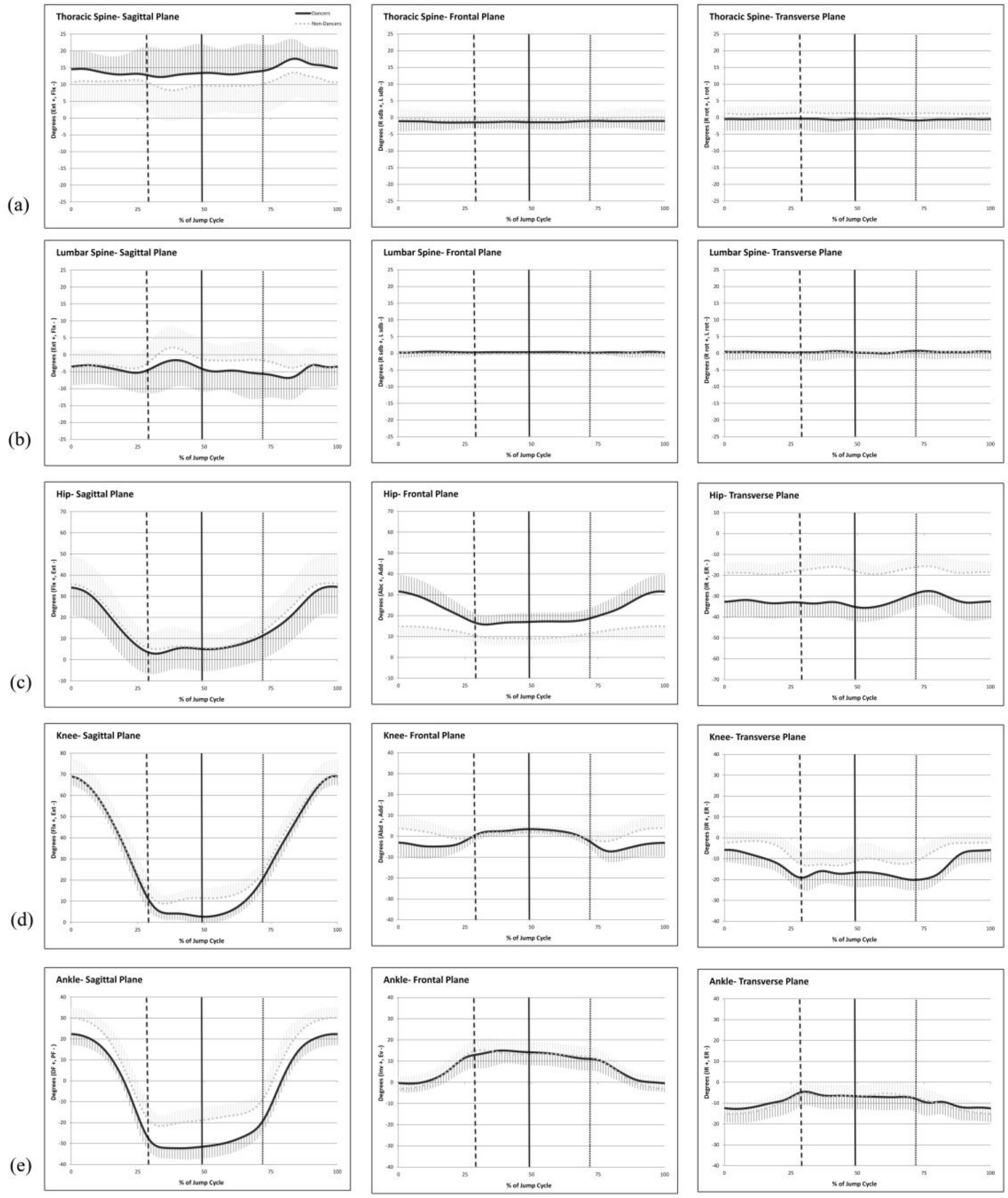

Figure 4. Mean kinematic profiles of the thoracic spine (a), lumbar spine (b), hip (c), knee (d), and ankle (e) for dancers and non-dancers during the sauté jump. Whiskers denote instantaneous SD of a kinematic variable for all subjects. Vertical dashed line indicates end of initial stance phase/beginning of early flight phase, solid vertical line indicates end of early flight phase/beginning of late flight phase, and vertical dotted line indicates end of pre-landing phase/beginning of final stance phase.

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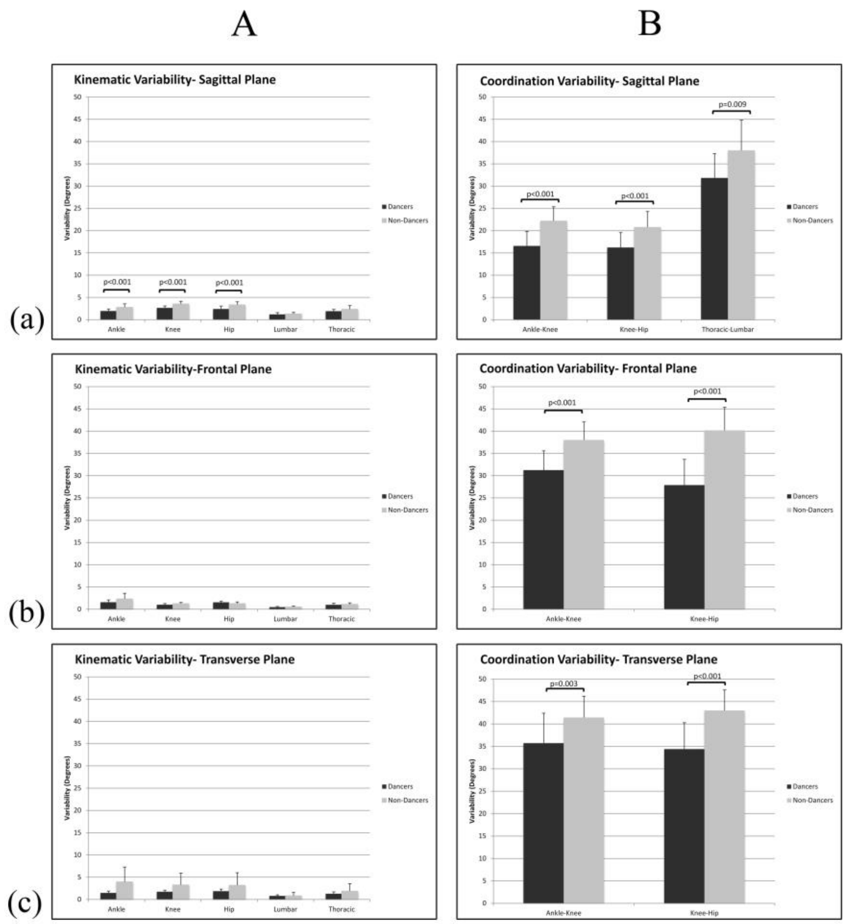

Figure 5. Variability in dancers and non-dancers. A: Single joint kinematic variability, expressed as averaged standard deviation of joint angles in the sagittal plane across repeated trials of the jump cycle; B: Inter-segmental coordination variability, expressed as averaged angular deviation of coupling angles across repeated trials of the jump cycle. (a) Sagittal plane; (b) Frontal plane; (c) Transverse plane.

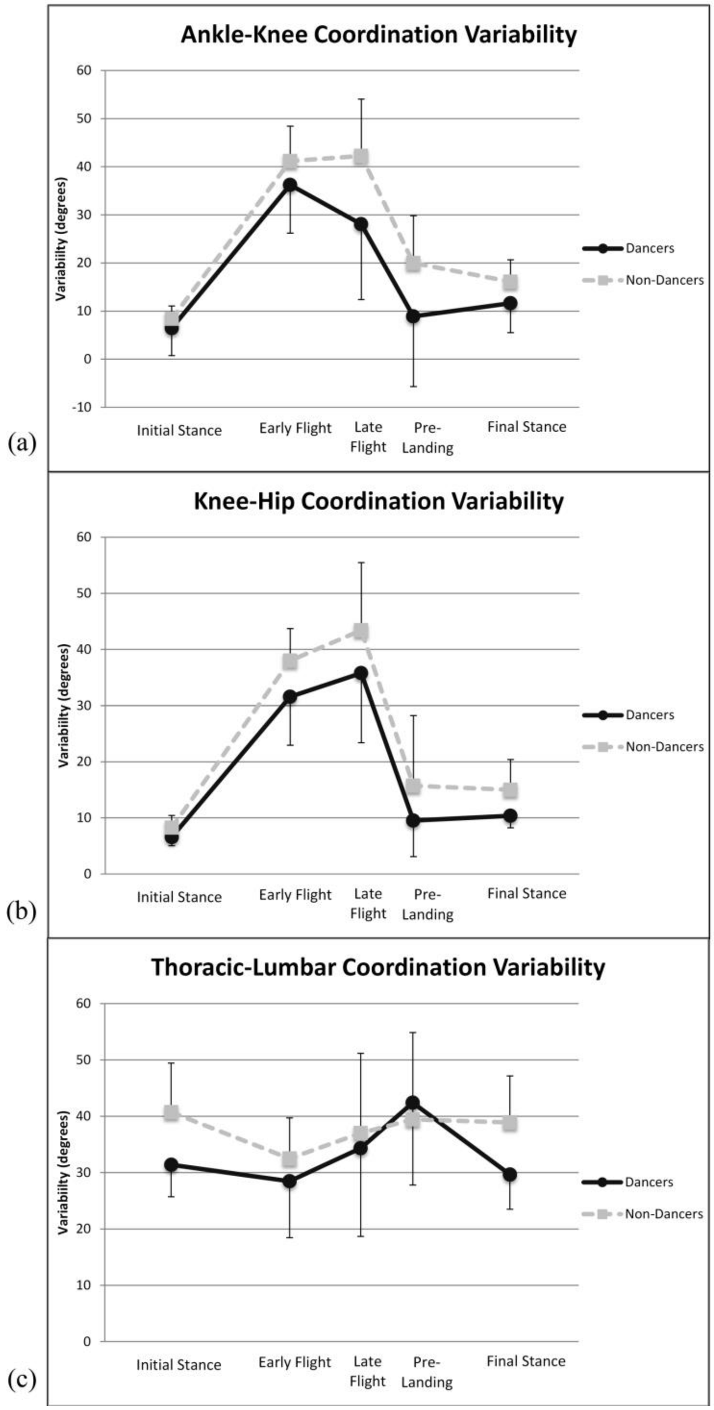

Figure 6. Sagittal plane inter-segmental coordination variability between joints across the jump cycle, expressed as average angular deviation during five phases of the jump. (a) Ankle-Knee coordination variability; (b) Knee-Hip coordination variability. (c) Lumbar-Thoracic coordination variability.

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Table 1. Demographic characteristics of subjects.

Characteristic	Dancers (n=10)	Non-Dancers (n=10)	P value
Age (years)	27.1 ± 3.5	24.8 ± 2.2	.09
Mass (kg)	58.4 ±5.9	57.7 ± 7.1	.81
Height (m)	1.65 ± 0.1	1.63 ± 0.1	.45
Dance Training (years)	20.8 ± 5.3	not applicable	