Time to Stability Differences Between Male and Female Dancers After Landing From a Jump on Flat and Inclined Floors

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Objective: To determine the effect of gender and inclined floor on time to stability (TTS) after landing from a vertical jump.

Design: This study used a repeated measures design with male and female professional dancers landing on a flat and 4 inclined floors. A repeated measures univariate analysis of variance (gender $\times$ floor) was performed on TTS in the anterior-posterior and medial-lateral directions.

Setting: Biomechanics laboratory.

Participants: Twenty-three female and 13 male professional dancers.

Independent Variables: Gender and floor inclination (flat, posterior, anterior, lateral, and medial).

Main Outcome Measures: Time to stability in the anterior-posterior and medial-lateral directions after landing from a vertical jump.

Results: Female dancers exhibited longer TTS in both directions ($P \leq 0.05$). Floor inclination or the interaction of gender $\times$ floor did not have an effect on TTS ($P > 0.3$).

Conclusions: Female dancers exhibited longer TTS after landing from a vertical jump compared with their male counterparts. This balance difference may be a factor related to the higher rate of ankle sprain among female dancers. Additionally, professional dancers exhibited similar TTS when landing on flat and inclined floors.

Key Words: dancers, time to stability, inclined floor, ankle sprain, landing

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INTRODUCTION

Similar to jumping-intensive sports, ankle sprain is the most common traumatic injury in dancers[1,2] with 29% to 37% of dancers spraining their ankle in a year.[3,4] Although ankle sprain is often considered a benign injury with quick recovery, it frequently leads to long-term disability.[5,6] As more studies on the epidemiology of dance injuries are published, it has become apparent that there is a gender disparity with female dancers having 20% to 55% higher relative frequency of ankle sprains than male dencers.[2,4]

The etiology of ankle sprains is multifactorial; however, balance deficits have been consistently identified as a predictor of ankle sprain by multiple studies.[7–14] Two studies that found no relationship between balance and ankle sprain[15,16] grouped together athletes from a variety of heterogenous sports (such as gymnastics and football) and had a low number of participants per sport. The possible differences in the mechanism of ankle sprains between sports and differences in the methodology used for measuring balance may explain the lack of significant findings in these 2 studies. A recent systematic review[17] found that "a consensus (albeit not unanimous) of evidence indicates that poor postural control was associated with increased risk of ankle sprain." A commonly used biomechanical measure of balance is time to stability (TTS), which signifies the time point when the range of variation of a biomechanical variable [such as the ground reaction force (GRF)] returns to baseline variation after landing from a jump. Given that landing from a jump is the task that accounts for the majority of ankle sprains in dancers[3,4] and the value of using objective measures of balance as predictors of future ankle sprains, a study that investigates potential gender differences in measures of balance after landing from a jump in dancers is needed. Therefore, the primary hypothesis of this project is that female dancers will exhibit increased TTS after landing from a vertical jump when compared with male dancers.

A secondary area of importance in respect to lower extremity injury in dancers is the effect of floor inclination. Stage flooring is often "raked" or declined toward the viewers to create clearer views of action occurring at the back of the stage. Two epidemiological studies[18,19] have provided preliminary evidence that raked stages are risk factors for injury, and 3 recent biomechanical studies[20–22] have shown that statistically significant differences in lower extremity angles exist in the way that dancers stand and land from a jump. The effect of inclined floor on balance measures of male and female dancers landing from a vertical jump has not been investigated.

Therefore, a secondary research question of this study was to investigate if dancers exhibit increased TTS after landing from a vertical jump on an inclined floor compared with a flat floor.

METHODS

Subjects

Thirty-six professional dancers (23 women and 13 men) were recruited [women: 28 (5) years, 167 (5) cm, 58 (6) kg; men: 26 (4) years, 177 (7) cm, 71 (6) kg]. The majority of dancers (87% of women and 91% of men) self-identified their primary genre as modern, ballet, or both. Exclusion criteria were a history of injuries and/or diseases that could affect the biomechanics of landing, such as lower extremity fractures or a history of ankle sprain; a history of injuries and/or diseases that would render unsafe the execution of the protocol; and obesity (body mass index greater than 30 kg/m^2).

Instrumentation

The force plate was an OR6-5 AMTI biomechanical platform (AMTI, Watertown, Massachusetts). The kinetic data were sampled at 2500 Hz as appropriate for fast athletic maneuvers.[23]

Experimental Protocol

Subjects were informed of the study protocol and total time needed for testing. All risks and possible harms, as described in the consent form, were verbally explained. All subjects completed a medical history questionnaire, signed a consent form approved by the institutional review board, and were measured for height and weight. Subjects wore their own athletic shoes during testing.

After a 10-minute bike warm-up, the maximum single leg jump height was determined for the dominant leg of the subjects similarly to the procedure that has been described by previous investigators.[24] All subjects were right leg dominant, defined as the preferred leg that would be used to kick a ball for maximal distance. Then, the subjects were instructed to perform a vertical jump (referred by dancers as a sauté) starting by stepping onto the force plate with their right leg, jumping vertically high enough to lightly touch with their head a plastic ball that was positioned at 50% of their maximum single leg jump height, landing on their right leg, sticking the landing, and staying as motionless as possible for 20 seconds. The effect of the arms was minimized by asking the subjects to keep their arms crossed against their chest.[25] Trials were repeated when they were judged as nonacceptable (such as when subjects lost their balance or did not land with the entire foot on the force plate) by one of the 2 investigators who were closely monitoring the jumps. Three successful landings were performed for each subject on each 1 of the 5 floor conditions (Figure 1). The order of the 5 different slope conditions was randomized. Subjects did not receive any instructions on the landing technique to avoid a coaching effect.

To replicate the flat and "raked" stages effect, it was necessary to construct flooring (2 wedges and 1 flat surface), which could be attached to the surface of the force plate. The slope of 3.6° was achieved in both wedges. Details on the construction of the wooden floors and validation experiments have been reported elsewhere.[20]

Data Processing

Time to stability in the anterior-posterior (APTTS) and medial-lateral (MLTTS) directions were calculated as per Colby et al[26] for each landing using custom software (Matlab; MathWorks, Natick, Massachusetts). Ground reaction force data from the initial contact of the landing phase of the sauté and the subsequent 5 seconds were used to calculate means and SDs for each trial. After this, a cumulative average of each GRF signal was computed at each data starting at the initial contact. The time when this cumulative average went and remained within the "mean GRF of the trial + 0.25 SD" for the remainder of the trial was defined as the TTS (Figure 2). This threshold was for the cumulative average and not for individual data points that sometimes exceeded the threshold but did not cause the cumulative average to exceed "mean GRF+0.25 SD." We chose to use data from the initial 5 seconds as opposed to the more traditional 20 seconds because of evidence that it may be a more sensitive measure.[27]

Statistical Analysis

This project used a repeated measures experimental design with gender (male/female) and floor inclination (flat/posterior/anterior/medial/lateral) as the independent variables and MLTTS and APTTS as the dependent variables. All data were entered into statistical software (SPSS 13.0; SPSS, Inc, Chicago, Illinois) and analyzed with a 2 × 5 analysis of variance (ANOVA).

Descriptive statistics (mean and SD) and effect sizes were produced, and the data were inspected and tested to ensure that the assumptions for data normality, variance equality, and sphericity of the univariate repeated measures ANOVA were not violated. It was decided a priori to perform post hoc tests between the flat floor condition and each one of the inclined floors if the main effect for floor or the interaction gender × floor was significant. The α level was set a priori at 0.05. Cohen *d* statistic of effect size was calculated to give a more complete picture of the effect of the independent variables on the dependent variables. The effect size is defined as trivial if it is <0.2, small if 0.2 to 0.5, medium if 0.5 to 0.8, and large if >0.8.[28]

RESULTS

The ANOVA revealed that there was a main effect for gender for APTTS ($F_{1,34} = 4.1$; $P = 0.05$) and MLTTS ($F_{1,34} = 6.4$; $P = 0.02$) with medium effect sizes. Female dancers exhibited APTTS and MLTTS values that were 110 and 134 milliseconds, respectively, longer than those of male dancers when collapsed across all 5 floor conditions. There was no effect of floor or the interaction of floor × gender on APTTS ($F_{4,136} = 0.94$; $P = 0.44$ and $F_{4,136} = 1.21$; $P = 0.3$, respectively) and MLTTS ($F_{4,136} = 0.26$; $P = 0.9$ and $F_{4,136} = 0.39$; $P = 0.81$, respectively), with trivial or negative effect size (Table).

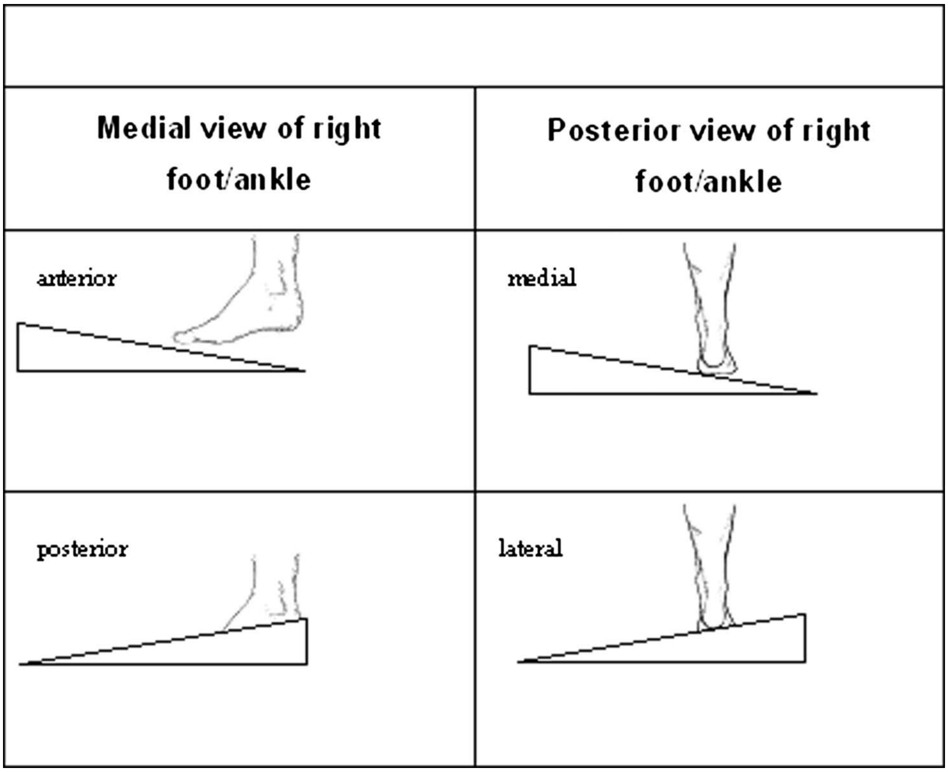

FIGURE 1. The 4 inclined floor conditions (originally published in Clinical Biomechanics).[20]

DISCUSSION

The main finding of this project is that female dancers landed after a jump with increased TTS compared with their male counterparts, confirming our first hypothesis. Both statistical significance tests and effect size calculations confirmed that female dancers in this study landed after a vertical jump with measurable TTS differences compared with male dancers. Although taking this additional time to stabilize may be reflective of an increased injury risk hazard for female dancers, the clinical significance of the measured TTS difference in a more natural environment is unclear. This finding may add to the body of work of factors associated with gender disparity in ankle sprain rates among dancers and may provide new insight on strategies that can be used to ameliorate this disparity.

The mechanisms responsible for the longer TTS in female dancers are unknown; however, it seems that

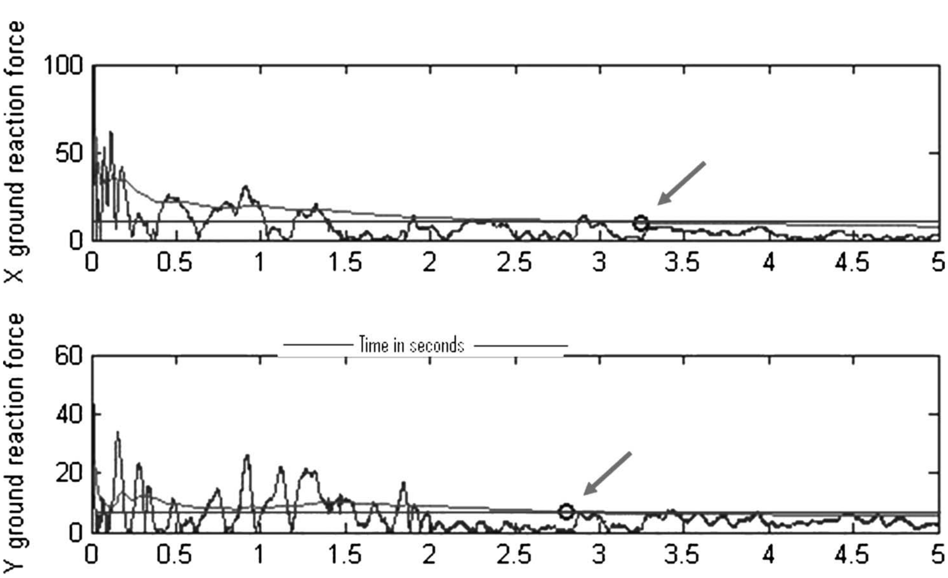

FIGURE 2. Time to stability calculations in the anterior-posterior and medial-lateral directions defined as the time (arrows) when the cumulative average (light gray lines) went and remained within ''mean GRF of the trial + 0.25 SD'' (horizontal black lines). Dark gray lines indicate GRF signal.

TABLE. Anterior-posterior and Medial-lateral Time to Stability Values (in Seconds) for Each Gender (Collapsed Across Floor Conditions) and Each Floor Condition (Collapsed Across Genders)

	Men	Women	Flat	Posterior	Anterior	Lateral	Medial
APTTS							
Mean (SD)	2.49 (0.17)	2.60 (0.22)	2.58 (0.19)	2.53 (0.25)	2.57 (0.21)	2.52 (0.22)	2.55 (0.20)
95% confidence interval	2.40-2.58	2.53-2.66	2.50-2.64	2.43-2.60	2.48-2.62	2.43-2.58	2.48-2.63
Effect size for gender	0.56 (medium)		Effect size for floor (compared with flat)	−0.22 (negative)	−0.04 (negative)	−0.29 (negative)	−0.015 (negative)
MLTTS							
Mean (SD)	2.70 (0.25)	2.83 (0.24)	2.77 (0.30)	2.74 (0.23)	2.80 (0.24)	2.76 (0.25)	2.76 (0.28)
95% confidence interval	2.61-2.78	2.77-2.90	2.66-2.87	2.66-2.82	2.71-2.89	2.67-2.84	2.66-2.86
Effect size for gender	0.53 (medium)		Effect size for floor (compared with flat)	−0.11 (negative)	0.11 (trivial)	−0.03 (negative)	−0.03 (negative)

proprioceptive feedback may play a role. Due to their shoes and gender-specific aesthetic demands, female classical dancers tend to spend more time training with their ankles in excessively plantarflexed positions, which may elongate the inert structures of the anterior ankle and subsequently reduce proprioceptive feedback. Ankle laxity has been linked to higher occurrence of ankle sprains in college athletes.[16]

Dancers receive balance training and instruction on proper landing techniques from an early age[29] and possess superior balance compared with nondancers[30,31]; however, the utilization of perturbations while balancing on unstable surfaces, which is a frequent component of proprioception training programs that have been effective in decreasing risk for future ankle sprain,[32,33]is rarely used in dance. Studies have reported that a large portion of female dancers who are fully participating in dance classes exhibit balance deficits.[34,35] It has been previously suggested that adding such proprioceptive training to dance practice may decrease ankle sprain injury rates[4,36,37] that are epidemic among dancers. Female dancers in particular may benefit from balance training with their ankles in a plantarflexed position to improve proprioception within that functional end range that they are required to perform. Balance measurements may have the potential to be used as measures of success of injury prevention programs and to measure return of balance to baseline levels in injured dancers.

A secondary finding of this study is that landing on inclined floors similar to "raked" stages did not cause dancers to land with an increased TTS, corroborating previous findings.[22] Besides the lack of statistical significance for the effect of floor on TTS, all effect sizes when comparing flat floor with each one of the inclined floors were negative or trivial. It seems that the increased risk for injury when dancing on "raked" stages is not due to the decreased balance but it may be due to changes in lower extremity angles[20] or, in the case of women, to its interactive effect with high-heel shoes.[22] However, it may be theorized that because the margin of error was smaller when landing on the inclined floors, dancers recruited the neuromuscular system more effectively to ensure that they stabilized quickly and decrease the risk of falling or injury.

Several limitations are recognized that call for a cautious interpretation of the findings of this study. This was a laboratory study in a controlled environment. It is unclear if dancers exhibit similar landing behavior when they are taking dance classes or performing or if an increased TTS predisposes dancers to ankle injury; a prospective biomechanical/epidemiological study is needed to answer this question. As it was discussed earlier, ankle sprain is a very common injury among dancers, making the recruitment of professional dancers with no history of ankle sprain a challenging task and resulting in a small sample size. Although the gender disparity in ankle sprains has been demonstrated in epidemiological studies with participants whose age and professional level were similar to our sample,[2,4] future studies of TTS should involve younger dancers who probably have better potential to benefit from balance training. The reason that female dancers are more predisposed to ankle sprains than male dancers is likely multifactorial; gender differences in choreography, fatigue, footwear, and dancing with the ankle in a more plantarflexed position have been suggested as explanations for the gender disparity.[4,22,38]

CONCLUSIONS

The current study identified balance differences between female and male dancers after landing from a standardized vertical jump task. These differences may be related to increased ankle sprain risk among female dancers. Inclined floor did not cause dancers to land with decreased balance compared with flat floor; therefore, the findings of this study do not support the suggestion that the increased injury rate for dancers who perform on "raked" stages with flat shoes is related to balance.

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