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ORIGINAL

Analysis of Postural Stability in Response to External Perturbation Intensity in Dancers and Non-dancers

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Objective: The goal of this study was to systematically investigate the postural stability of dancers by providing unexpected perturbations.

Method: Six female dancers and college students participated in this study. Unpredictable wait-pull balance perturbations in the anterior direction were provided to the participants during standing. Three different perturbation intensities (low, moderate, and high intensity) were used by increasing perturbation forces. Spatial and temporal stability of postural control were measured by using margin of stability (MoS) and time to contact (TtC), respectively.

Results: Both MoS and TtC at moderate intensity were significantly greater in the dancer group than in the control group, but no significant differences were found at low and high intensities between the groups.

Conclusion: The present study showed spatial and temporal stability of dynamic postural control in dancers. We found that the dancers were more spatially and temporally stable than the ordinary participants in response to unexpected external perturbation when the perturbation intensity was moderate at two extreme intensity levels (low and high).

Keywords: Dancer, Postural stability, External perturbation, xCoM, Margin of stability, Time to contact

INTRODUCTION

Dancers have high levels of motor control and balance abilities (Kiefer et al., 2011, Simmons, 2005b). This can be attributed to the specific nature of dance training (Perrin, Deviterne, Hugel & Perrot, 2002), where the training techniques require balance to maintain dynamic stability in performing various dance motions, and flexibility to create a wide range of joint movements. From a mechanical perspective, this superior ability to maintain balance can be interpreted as having quick musculoskeletal responses to external stimuli and faster recovery of the ability to maintain posture through stronger proprioception (Kiefer et al., 2011).

In the general population, injuries and accidents, which are most closely associated with postural maintenance, can be attributed to postural imbalance from unexpected environmental changes. Being pulled, colliding with something, and falling can cause sudden postural changes, which can lead to imbalance due to external force. According to a report by Zecevic, Salmoni, Speechley and Vandervoort (2006), motor control aspects such as body coordination, slow body reaction speed, low agility, and sudden postural change account for 50% of falls among the elderly, which can result from injuries caused by physical imbalance or environmental causes such as obstacles.

The definition of perturbation used in most precedent studies referred to the environment that gives unpredictable and sudden external stimuli (Pai, Rogers, Patton, Cain & Hanke, 1998; Schulz, Ashton-Miller & Alexander, 2006). Perturbation studies in the fields of biomechanics and motor control have been conducted for the purpose of recreating environmental changes that can occur suddenly among the general and elderly populations (Pai et al., 1998; Hasson, Van Emmerik & Caldwell, 2008; Hyodo et al., 2012). Precedent studies on perturbation mostly analyzed center of pressure (CoP) to identify postural maintenance and changes (Sturnieks et al., 2013; Piirainen, Linnamo, Cronin & Avela, 2013; Toebes, Hoozemans, Dekker & van Dieën, 2014). However, the importance of the relationship between whole-body center of mass (CoM) and posture is being emphasized in various studies that reported that CoM would be a more accurate variable than CoP for predicting the posture during dynamic postural maintenance (Hasson et al., 2008). Extrapolated center of mass (xCoM), which takes into account the CoM velocity, has been quantified and used to examine the dynamic stability (Hof, Gazendam & Sinke, 2005). Spatial and temporal stability of dynamic movements have been quantified using margin of stability (MoS) and time to contact (TtC), which are calculated as the minimum distance and time to reach base of support boundary from xCoM, respectively (Hof et al., 2005).

Studies on the balance ability of dancers have examined changes in CoP values to measure balance ability in the standing position (Gerbino, Griffin & Zurakowski, 2007), by comparing CoP values of dancers with those of non-dancers to test one-footed balancing in a demi-pointe position of ballet dancers (Da Costa, Nora, Vieira, Bosch & Rosenbaum, 2013), and investigated proprioceptive strategy for the maintenance of dynamic balance in dancers by using the star excursion balance test (Hutt & Redding, 2014), and the effect of visual information on balance ability (Kiefer et al., 2011). Most of these studies either used CoP analysis or balancing function tests to examine balance ability in dancers. Moreover, a perturbation study on dancers (Simmons, 2005a) used a force platform and electromyography to test the dynamic stability of dance movements.

With respect to recent research trends in Korea, studies have investigated the stability of dancers during dance motion by using vertical ground reaction force and CoP (Kwon & Woo, 2016; Park, Kim & Lee, 2014) and conducted static balance ability during single-footed standing with eyes open and closed by using CoP analysis (Youm, Park & Seo, 2007). This indicates that most of the studies on the stability of dancers have been conducted under static conditions. Meanwhile, studies on the dynamic posture of dancers have examined changes in CoM during an arabesque turn motion with and without use of the upper extremities (Park & Kim, 2009) and analyzed lower extremity segments during the Fouette' turn (Lee & Oh, 2012). Another study reported that greater vestibular equilibrium would be associated with rotational motion training (Park & Lim, 2008). These studies have showed superiority of dynamic stability of dancers performing the specific dancer motions or the motions the dancers are familiar with. However, the spatial and temporal stability of postural control in dancers are poorly understood.

The objective of the present study was to investigate spatial and temporal stability of postural control in dancers. We hypothesized that dancers would have a greater MoS and longer TtC as compared to non-dancers in response to external perturbation.

METHODS

1. Participants

The participants in the present study consisted of 6 female dancers and 6 female with no dance experience (non-dancers). The physical characteristics of the participants are as shown in Table 1.

Table 1. Characteristics of the participants

Variable \ Test	Dancers	Controls	t	p
Height (cm)	161.67 ± 3.39	160.85 ± 2.90	.443	.667
Weight (kg)	48.75 ± 2.40	50.68 ± 4.20	-.978	.351
Age (years)	26.33 ± 1.72	23.33 ± 3.67	2.115	.061
Dance careers (years)	13.50 ± 3.45	0		

Data are presented mean ± SD, significant at $^{*}p < .05$.

2. Measurements

The present study used 6 high-speed infrared cameras to acquire images of motions during stimulation by perturbation (100 field/sec, Shutter speed of 1/500, and 6-Hz low-pass filter), and 19 reflective markers were attached throughout each participant's body to obtain positional data (Figure 1). The perturbator equipment used for stimulation by perturbation was developed in-house (DC 90W motor, decelerator, linear guide, spring, frame, sensor, and switch) and designed to be worn on a belt around the participant's waist, with which a waist-pull force is applied to pull the participant forward by the force of the spring connected to the motor. A preliminary experiment was conducted to establish the perturbation intensity levels. When 8 different perturbation intensity levels (2, 4, 7, 9, 13, 20, 24, and 30 kg) were applied in all the participants, the perturbation intensity of 20 kg generated when the CoM moved as all the participants lifted their feet completely off the ground was designated as a high degree of difficulty. Relative to this high degree of difficulty, a perturbation intensity of 9 kg, which was the highest weight where the participants did not lift their feet at all, was designated as a low degree of difficulty. By applying the median value between the two designated degrees of difficulty points, 13 kg was set as a moderate degree of difficulty. During the experiment, the participants were instructed to maintain a standing position while facing forward in natural state, while the basal plane boundary was marked after measuring the shoulder width of each participant. Each participant was controlled to make sure not to deviate from her own basal plane,

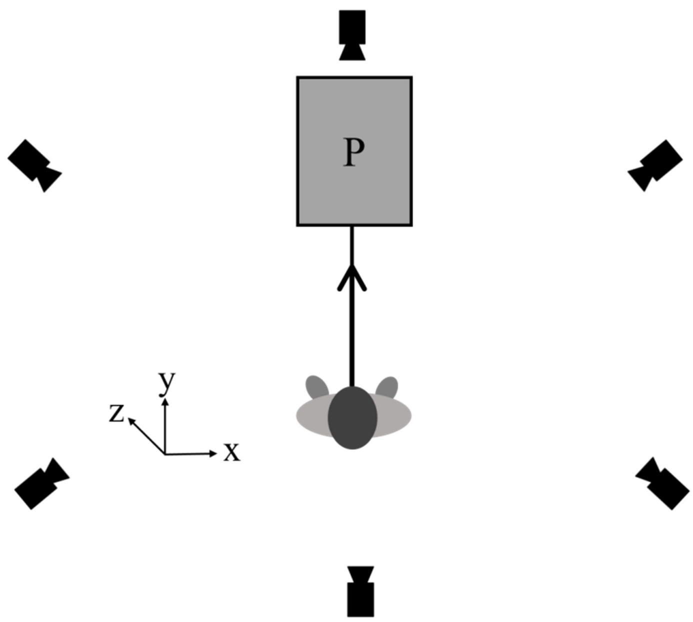

Figure 1. Experimental setup. Waist-pull perturbation equipment (P).

Table 2. The formulae for calculating xCoM, MoS, and TtC

	Formula	Study
xCoM	$\mathrm{xCoM} = p + \frac{v}{w_o},\ w_o = \sqrt{\frac{g}{l}}$	Hof et al. (2005)
Margin of stability (MoS)	$\mathrm{MoS} = \min(p_{\max} - \mathrm{xCoM})$	
Time to contact (TtC)	$\mathrm{TtC} = \min\left(\frac{p_{\max} - \mathrm{xCoM}}{v}\right)$	

$\min(\cdot)$: a minimum function; $p_{\max}$: the anterior-posterior location of the toe marker; p and v: the anterior-posterior position; w_o: the angular natural frequency of a non-inverted pendulum; g: gravitational acceleration; l: the pendulum length.

and the three predetermined intensity levels were applied in random order.

3. Data processing

1) CoM calculation

The positional data obtained from 6 infrared cameras were used to calculate the CoM values, which were analyzed by using the Kwon3d XP software.

2) MoS and TtC calculation

Hof et al. (2005) mentioned that for estimation of dynamic stability, xCoM values obtained from using a formula based on the inverted pendulum model principle (Geurtsen, 1975; Winter, 1995a) can make more-accurate estimation than CoM values. Therefore, analysis was performed by using two methods with recalculation of xCoM values from the positional data obtained and by using the values in the formula. The first method was used to analyze MoS, the minimum distance (m) from the base of support boundary to xCoM, while the second method was used to analyze TtC, the minimum time (sec) from the base of support boundary to xCoM. The base of support boundary in the present study was defined as the toe marker position in anterior-posterior axis. The calculation formulae are shown in Table 2, and the measurement variables are shown in Figure 2.

4. Statistical analyses

For data processing, two-way repeated-measures analysis of variance (ANOVA) was used to compare between the perturbation intensities (Low: L, Moderate: M, and High: H) and between the groups (dancer and control groups). For the post hoc test, an independent *t* test was performed to compare between the groups (2 groups) and one-way ANOVA was used to compare the intensity levels (3 intensity levels). All statistical analyses were performed by using SPSS Statistics 21.0 with a significance level of 5%.

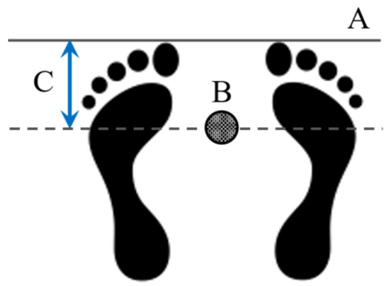

Figure 2. Measurement variables: base of the support boundary (A), xCoM (B), and margin of stability (distance) and time to contact (time) (C).

RESULTS

In each group, no significant differences in height and weight were found among the participants as shown in Table 1 (p > .05). The MoS values measured during stimulation by perturbation are shown in Figure 3. Significant differences were found in the interaction group * intensity [$F_{(2,20)}$ = 11.891, p < .001] and main-effect intensity [$F_{(2,20)}$ = 53.026, p < .001, L > M, M > H, L > H], but no significant differences were found between the main effect groups [$F_{(1,10)}$ = 4.722, p > .05].

The TtC values measured during stimulation by perturbation are shown in Figure 3. Significant differences were found in the interaction group * intensity [$F_{(2,20)}$ = 3.504, p < .05] and main-effect intensity [$F_{(2,20)}$ = 30.258, p < .001, L > M, M > H, L > H], but no significant differences were found between the main effect groups [$F_{(1,10)}$ = 2.987, p > .05].

Significant differences in MoS and TtC were found between the dancer and control groups at moderate intensity, but no significant differences were found at low and high intensities.

DISCUSSION

The objective of the present study was to investigate the postural stability in dancers, who were demonstrated to have superior balance ability than non-dancers. To achieve this objective, the present study established the hypothesis that the dancers will have greater MoS and shorter TtC than the non-dancers.

With respect to the balance ability of dancers, when visual cues are

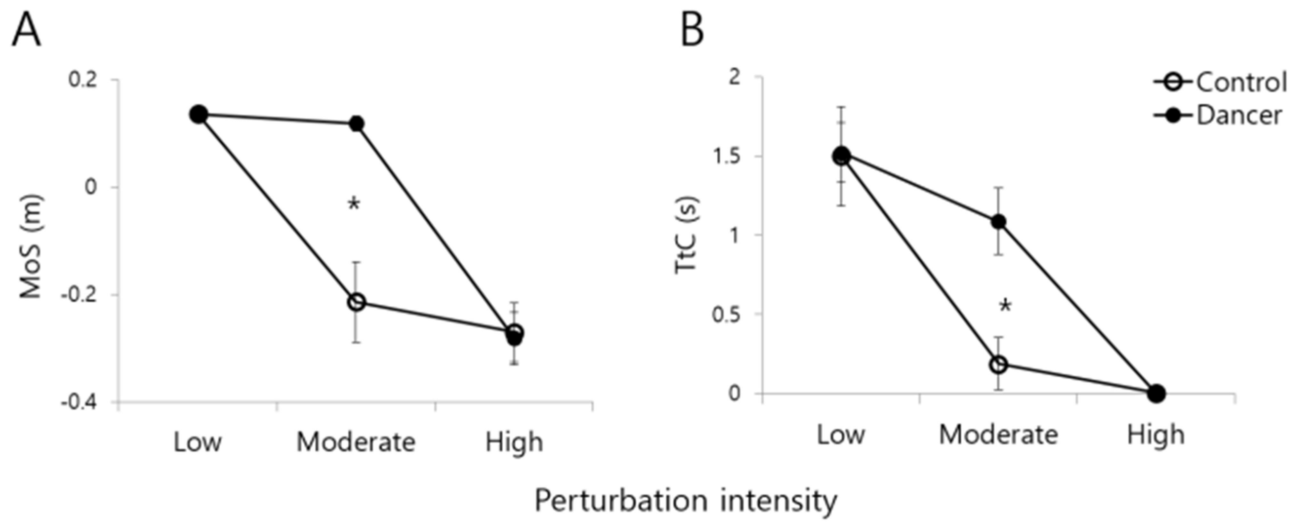

Figure 3. Margin of stability (MoS) (A) and time to contact (TtC) (B) across perturbation intensity conditions between the groups. The asterisk indicates a significant difference between the groups at moderate intensity (p < .05).

applied in static state, dancers show superior bodily coordination than non-dancers (Kiefer et al., 2011). However, according to many studies, the paradigm of the ability to maintain such static stability may vary depending on the motion the dancer tries to express or on external environmental factors (Kiefer et al., 2011; Gerbino et al., 2007; Hugel, Cadopi, Kohler & Perrin, 1999; Schmit, Regis & Riley, 2005). Kiefer et al. (2011) emphasized the importance of training in improving dynamic abilities for continuous performance by dancers, which is because dance has the purpose of combining dynamic and rhythmical motions, and the ability to quickly change the dynamic balance ability and maintaining stability are important elements in connecting the motions that are generated under such situation.

Among the studies that analyzed the dynamic stability of dancers, a study by Gerbino et al. (2007) indicated that when a balance test was performed to test the dynamic balance abilities of dancers, the results showed that dancers had excellent ability to maintain their balance even when landing quickly after moving the CoM and standing on an uneven surface. Moreover, Hutt and Redding (2014) indicated that dancers had superior dynamic stability than non-dancers, which was proven through testing of balance ability based on the presence or absence of visual cues that are most closely associated with the practice environment of dancers. However, when the dynamic stability of dancers was exposed to the general environment, identifying the type of bodily strategies used should provide the basic data for finding the method that can maintain dynamic stability under sudden changes in external environment.

Hasson et al. (2008) mentioned that CoM was more accurate than CoP in predicting the posture that can maintain dynamic balance. Meanwhile, Hof et al. (2005) indicated that xCoM is a predicted value that can prove which position the CoM, calculated by using a formula, would move to in the future. As such, xCoM can provide more-accurate information for predicting dynamic stability than CoM. Moreover, a study on dynamic stability using xCoM suggested MoS and TtC as the variables for quantifying spatial and temporal stability of postural control (Hasson et al., 2008).

With respect to precedent studies on dynamic stability that applied MoS, such studies include testing of the ability to control dynamic stability during going-downstairs task (Bosse et al., 2012; Novak, Komisar, Maki & Fernie, 2016) and the size of MoS in a mediolateral direction during gait and dynamic stability of gait speed (Hak, Houdijk, Beek & van Dieën, 2013). Meanwhile, studies that examined dynamic stability by applying TtC reported that calculated TtC can be used to make better predictions on situations that follow stimulation by perturbation (Hasson et al., 2008; Wheat, Haddad & Scaife, 2012).

In the present study, greater MoS and TtC values in the dancers than in the non-dancers were found at moderate perturbation intensity, but no significant differences were found between the non-dancers and dancers at low and high intensities. These results reflect the fact that MoS, the minimum distance, and TtC, the minimum time from the boundary of the base of support to xCoM, appeared greater, which can be interpreted as dancers having enhanced spatial and temporal stability than non-dancers.

According to studies by Bosse et al. (2012) and Aprigliano, Martelli, Tropea, Micera and Monaco (2015), healthy participants during gait showed greater MoS values under an unperturbed environment than that in a perturbed environment (platform-type surface or visual cue). These studies suggested that dynamic stability was greater in the unperturbed environment, which are consistent with the finding of the current study that showed greater dynamic stability in the dancers by having greater MoS than in the non-dancers.

A study by Lugade, Lin and Chou (2011) reported that elderly people with experience of falls showed shorter TtC than elderly people without such experience. This may indicate that longer TtC in participants implies superior balance ability. This results in the previous study is consistent with the findings in the present study that showed dancers had longer TtC than non-dancers.

The current study also showed that significant differences in MoS and TtC between the dancers and the non-dancers at moderate intensity. This result can be interpreted as dancers being able to better withstand the same magnitude of external perturbation. In other words, despite that the dancers and non-dancers had similar physical characteristics in terms of weight (t = .978) and height (t = .443), the non-dancers were disturbed to a greater degree than the dancers with the same intensity of external perturbation.

In conclusion, the present study showed the evidence that dancers had a greater spatial and temporal stability of postural control than non-dancers in response to external perturbation

CONCLUSION

The present study performed temporal and spatial analyses of postural stability in dancers. MoS and TtC were used to quantify the spatial and temporal stability of postural control. The dancers showed greater MoS and longer TtC than the non-dancers at a moderate intensity of perturbation. Based on these findings, we demonstrated that the dancers had superior ability to maintain dynamic stability than the non-dancers in postural control when perturbation intensity is intermediate between two extremes.

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