

Characteristic relationship between the centre of pressure and the centre of mass during quiet standing in female ballet dancers

Abstract

The purpose of this study was to examine the characteristics of centre of pressure (COP) and centre of mass (COM) fluctuations in ballet dancers standing quietly. Ten healthy young women performing classic ballet dance as recreational exercise (dancer group) and 10 healthy non-ballet dancers young women who were not ballet dancers (control group) participated in this study. Participants were instructed to maintain three standing positions as steadily as possible (two-legged stance, one-legged stance, and tiptoe stance) with their eyes open. The COP and COM displacements, the distance between COP and COM displacements (COP-COM distance), and the 95% confidence ellipse areas of the COP and COM in the anterior-posterior and mediolateral directions were calculated to assess postural stability. The mean absolute value of the COP-COM distance and the absolute value of the mean COP-COM distance in each direction during one-legged standing in the dancer group were shorter than these values in the control group. These results suggest that the COP fluctuates more closely and evenly, in both directions, around the COM during one-legged standing in athletes with superior postural stability, which would provide a basis for feedback training using both COP and COM displacements for improving static balance.

Keywords: centre of mass, centre of pressure, postural control, static balance

Volume 1 Issue 2 - 2017

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Received: February 21, 2017 | **Published:** May 18, 2017

Introduction

Some sportspersons, such as gymnasts or dancers require superior postural stability to maintain their balance on a narrow base of support (BOS), such as a balance beam or on their tiptoes.^{1,2} However, Schmit et al.³ indicated that there were no differences in the path length and variability of centre of pressure (COP) sway between ballet dancers and non-dancers during static standing. Moreover, Tanabe et al.⁴ also reported an absence of differences in the path length and area of COP sway between ballet dancers and non-dancers when standing on tiptoes. It is still unclear how the COP and the body's centre of mass (COM) are controlled under the challenging conditions such athletes face.

As the relationship between COP and COM, the difference between COP and COM positions (COP-COM distance) has been investigated in terms of postural stability in static balance.⁵ A longer COP-COM distance is indicative of a greater body acceleration during quiet standing.^{6,7} Mani et al.⁸ reported that COP-COM distances were longer and that the mean displacements of COP were located more laterally from the COM during one-legged standing in an older group compared to a younger group.

The purpose of this study was to examine the characteristics of COP and COM fluctuations during quiet standing for possible differences between ballet dancers and non-dancers. Ballet dancers possess superior postural stability compared to non-dancing controls.²⁻⁹ We hypothesized that: the COP fluctuates around the COM closely and evenly in ballet dancers compared to normal control, based on the previous study.⁸

Material and methods

Participants in this study comprised 10 healthy young women

participating in classical ballet dance as recreational athletes (Dancer group) and 10 healthy young women who did not do ballet (Control group), all without any known neurological or motor disorders. Anthropometric data were recorded for each participant (Table 1). In the dancer group, the average years of dancing experience was 15.1±4.2 years (range: 7-20 years), and the average time per week spent dancing was 7.4±3.6 h. The dancers with a past history of fracture or sprain were excluded. All study protocols were approved by the ethics committee at the institution where the study took place, and written informed consent was obtained from all participants according to the Declaration of Helsinki.

Table 1 Anthropometric data were recorded for each participant

	Dancer (N=10)	Control (N=10)	
Age(years old)	23.1±1.2	22.6±1.3	
Height (cm)	156.7±5.1	157.9±5.0	
Body weight(kg)	44.5±2.2	53.0±3.6	*
Dominant foot	Right: 9Left: 1	Right: 10	
Foot length(cm)	22.8±1.1	23.0±1.0	
Foot width(cm)	8.8±0.7	9.1±0.4	
mean±SD			*: p <0.05

Kinematic data were collected using a six-camera 3D motion analysis system (Motion Analysis Corporation, Santa Rosa, CA, USA) with a sampling frequency of 200 Hz. Twenty-four reflective markers were placed on the participant. The COM in the anterior-posterior (AP) and mediolateral (ML) directions was calculated based on the 14 body segments and an anthropometrical model.¹⁰ A force plate (Kistler, Winterthur, Switzerland) was used to calculate

the coordinates of the COP in the AP and ML directions. Force plate signals were collected at a sampling frequency at 1000 Hz and synchronized with the motion analysis system.

Participants were instructed to stand barefoot with their hands on their hips in front of a visual target, located at eye-level height about 3 m away. The task involved maintaining a standing position as steadily as possible under three conditions (two-legged stance, one-legged stance, and tiptoe stance), with their eyes open. First, the participants were asked to stand with both feet together in each condition for 10 s. Then, the participants were required to maintain the starting posture (two-legged stance), to stand on a non-dominant foot (one-legged stance), or to stand on tiptoes (tiptoe stance), randomly, for a period of 30s.⁴ Participants were required to keep the big toe of the lifted leg (i.e., of the dominant limb), in line with the malleolus medialis of the supporting leg, and the knee cap face anteriorly in the one-legged stance. Participants repeated the task until the successful trial was performed each condition. Five minutes of rest was allowed between each condition.

All signals were processed off-line using MATLAB software (MathWorks, Natick, MA, USA). The motion analysis system data were filtered with a 20-Hz low-pass, 4th order, zero-lag Butterworth filter,¹¹ and the force plate data were filtered with an 8-Hz low-pass, 4th order, zero-lag Butterworth filter.¹² COP and COM path lengths per second (unit length), and the 95% confidence ellipse areas of the COP and the COM were calculated to assess postural stability.¹³ In addition, the mean COP-COM distance in the AP and ML directions were calculated to define the direction in the AP or ML during the COP fluctuated around the COM. Furthermore, the mean absolute value of the COP-COM distance (COP-COM_{close}, Equation 1) and the absolute value of sum of the COP-COM distance (COP-COM_{even}, Equation 2) were calculated as follows:

$$COP - COM_{close} = \frac{\sum_{t=1}^N |COP - COM|}{N} \quad (1)$$

$$COP - COM_{even} = \left| \sum_{t=1}^N (COP - COM) \right| \quad (2)$$

Where N shows the total sampling number. Thus, a shorter COP-COM_{close} indicates that the COP fluctuates more closely around the COM. On the other hand, a shorter COP-COM_{even} indicates that the COP fluctuates around the COM more evenly in the AP or ML direction. Unpaired t-tests were used to evaluate the differences between the groups. All statistical analyses were performed with SPSS 18 (SPSS, USA). Statistical significance was set at $p < 0.05$.

Results

Age, height, foot length and foot width, but not body weight, were not significantly different between the groups (Table 1). The mean body weight in the dancer group was significantly lighter than that of the control group. The mean values of COP-COM_{close} and COP-COM_{even} in each direction during one-legged standing in the dancer group were significantly shorter than those in the control group ($p < 0.05$; Figure 1). The mean values of COP and COM unit lengths, the 95% confidence ellipse area of COP and COM, and the mean values of COP-COM in the AP and ML directions in the one-legged stance were not significantly different between the groups. None of the kinetic parameters for two-legged stance or tiptoe stance differed significantly between the groups. In the kinematic aspects, the height of the calcaneus marker was significantly higher in the dancer group

than in the control group during tiptoe stance (Dancer: 13.6±3.2 cm, Control: 10.5±2.2 cm).

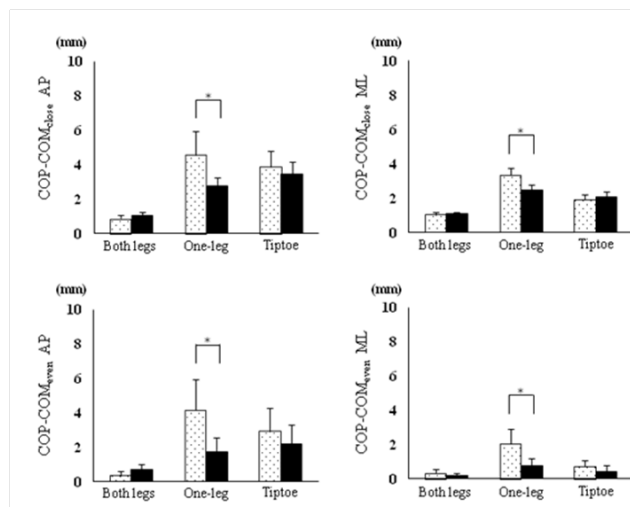


Figure 1 COP-COM_{close} and COP-COM_{even} in two directions under three conditions in both groups.

The mean values of the mean absolute value of the COP-COM distance per second (COP-COM_{close}) as well as the mean values of the absolute value of sum of the COP-COM distance (COP-COM_{even}) in each direction, under the one-legged stance condition in the dancer group were significantly shorter than in the control group * $p < 0.05$.

Discussion

The findings of this study were that the COP-COM distance decreased and the COP fluctuated more evenly around the COM in the AP and ML directions during one-legged standing in the dancer group than in the control group. On the other hand, the differences in the COP-COM parameters between the groups were not shown while standing on tiptoes or on both legs. The posture of tiptoe-standing is similar to that of 'relevé', which is a common pose in classical ballet.¹⁴ In this study, the height of the calcaneus marker was higher in the dancer group than in the control group during tiptoe stance. This might suggest that the dancer group had superior balance control, as they did not show increased sway, even though they were on average 3 cm higher off the ground, which would have induced the narrower BOS and the higher COM. No differences in COP-COM parameters were seen between the groups during two-legged stance. The long period of training would produce postural memories for a specific foot configuration.¹⁵

In conclusion, the biomechanical characteristics of maintenance of static balance in ballet dancers are that the COP fluctuates closely and evenly around the COM during one-legged standing. The finding of this study could provide useful information for the feedback training using COP and COM for postural stability in the fields of sports as well as rehabilitation.

Acknowledgements

None.

Conflict of interest

The authors declare no conflict of interest.

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